VALORIZATION OF AGRICULTURAL RESIDUES INTO BIOACTIVE COMPOUNDS: A SUPERCRITICAL EXTRACTION-BASED ECONOMIC PERSPECTIVE FOR TÜRKİYE

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

AYŞE İREM AKYILDIZ ARI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF ECONOMICS

SEPTEMBER 2025

Approval of the thesis:

VALORIZATION OF AGRICULTURAL RESIDUES INTO BIOACTIVE COMPOUNDS: A SUPERCRITICAL EXTRACTION-BASED ECONOMIC PERSPECTIVE FOR TÜRKİYE

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ABSTRACT

VALORIZATION OF AGRICULTURAL RESIDUES INTO BIOACTIVE COMPOUNDS:
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September 2025, 257 pages

This thesis investigates the potential of converting agricultural field and agro-industrial residues in Türkiye into high-value bioactive compounds through supercritical fluid extraction and evaluates the macroeconomic implications of this transformation. Rather than viewing residues as environmental burdens or energy sources, the study positions them as strategic bioeconomy inputs for the food, cosmetics, and pharmaceutical sectors. The research focuses on plant-based residues with industrial recovery potential and identified 285 product–residue pairs across 132 crops. Monte Carlo simulations estimated an annual average of 105 Mt theoretical, 50 Mt collectable, and 30 Mt dry residues. A systematic literature review provided data to construct SFE and Bioactive Scores, which were assessed using the AHP–TOPSIS methodology. Tomato (peels, pulp, seeds), grape (pomace, seeds), and olive (pomace, pruning residues) were identified as priority residues. Scenario-based calculations considered processing capacities of 1,000 tons (pilot), 10,000 tons (medium), and 30,000 tons (commercial) per year. Bulk extract production was estimated at 0.1–4.5 kt annually, yielding potential revenues of USD 120 million–1.5 billion. Specific compounds such as lycopene (USD 100–250 million), oleuropein (~USD 120 million), and hydroxytyrosol (USD 80–130 million) also showed strong market potential even at low volumes. Input–Output analysis demonstrated that, under the medium-scale scenario, bulk extract production could generate USD 400–800 million in output, USD 150–300 million in value added, and 500,000–750,000 jobs. Overall, the findings highlight that valorizing agricultural residues through SFE can provide not only firm-level profitability but also national-level benefits, enhancing economic efficiency, sectoral diversification, and alignment with circular bioeconomy policies.

Keywords: Agricultural Residue, Supercritical Fluid Extraction, Bioactive Compounds, Multi-Criteria Decision Making, Input-Output Analysis

ÖZ

TARIMSAL ATIKLARIN BİYOAKTİF BİLEŞİKLERE DÖNÜŞTÜRÜLMESİ: TÜRKİYE İÇİN SÜPERKRİTİK EKSTRAKSİYON TABANLI EKONOMİK BİR PERSPEKTİF

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Tez Yöneticisi: Doç. Dr. Münis Seven AĞIR YAĞCI

Eylül 2025, 257 sayfa

Bu tez, Türkiye'de tarımsal üretimden kaynaklanan saha ve agro-endüstriyel atıkların süperkritik akışkan ekstraksiyonu yoluyla yüksek katma değerli biyoaktif bileşiklere dönüştürülme potansiyelini ve bu dönüşümün makroekonomik etkilerini incelemektedir. Çalışma, tarımsal atıkları yalnızca çevresel bir yük veya enerji kaynağı değil, aynı zamanda gıda, kozmetik ve ilaç sektörleri için stratejik bir biyoekonomi girdisi olarak ele almaktadır. Araştırma, yalnızca Türkiye'de üretilen ve endüstriyel geri kazanım potansiyeli bulunan bitkisel kökenli atıklarla sınırlandırılmıştır. Bu kapsamda 132 ürün için 285 ürün–atık çifti belirlenmiş; Monte Carlo simülasyonu ile yıllık ortalama 105 Mt teorik, 50 Mt toplanabilir ve 30 Mt kuru atık miktarı hesaplanmıştır. Sistematik literatür taraması sonucunda elde edilen verilerle oluşturulan SFE ve Biyoaktif Skorlar, AHP–TOPSIS yöntemleriyle değerlendirilmiş ve domates kabuğu, posası ve çekirdeği, üzüm posası ve çekirdeği ile zeytin posası ve budama atıkları öncelikli gruplar olarak belirlenmiştir. Senaryo bazlı hesaplamalarda 1.000 ton (pilot), 10.000 ton (orta) ve 30.000 ton (ticari) kapasiteli işleme ölçekleri dikkate alınmıştır. Bulk ekstrakt üretiminin 0.1–4.5 kt aralığında olup 120 milyon–1.5 milyar USD gelir potansiyeli sunduğu görülmüştür. Spesifik bileşikler açısından likopen (100–250 milyon USD), oleuropein (~120 milyon USD) ve hidroksitirosol (80–130 milyon USD) düşük tonajlarda dahi yüksek ekonomik katkı sağlamaktadır. Girdi–Çıktı analizi, orta ölçekli senaryoda bulk üretimin Türkiye ekonomisine 400–800 milyon USD çıktı, 150–300 milyon USD katma değer ve 500–750 bin kişilik ek istihdam katkısı sunduğunu ortaya koymuştur. Bulgular, çok sektörlü dağılım stratejilerinin ekonomik verimliliği artırarak sektörel çeşitlenme ve döngüsel biyoekonomi politikalarıyla uyumu güçlendirdiğini göstermektedir.

Anahtar Kelimeler: Tarımsal Atık, Süperkritik Akışkan Ekstraksiyonu, Biyoaktif Bileşen, Çok Kriterli Karar Verme Süreci, Girdi-Çıktı Analizi

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LIST OF ABBREVIATIONS

AACEI	Association for the Advancement of Cost Engineering International
AB	Abstract
A-D	Anderson–Darling
AHP	Analytic Hierarchy Process
AR	Agricultural Residue
AW	Agricultural Waste
AWM	Agricultural Waste Management
BEPA	Biomass Energy Potential Atlas
C10–12	Food Sector
C20	Cosmetics Sector
C21	Pharmaceuticals Sector
CAGR	Compound Annual Growth Rate
CEC	California Energy Commission
CIGR	International Commission of Agricultural and Biosystems Engineering
CI	Consistency Index
CO_2	Carbon Dioxide
COL	Cost of Labor
COM	Cost of Manufacturing
CPA	Classification of Products by Activity
CR	Consistency Ratio
CRM	Cost of Raw Material
CUT	Cost of Utilities
CV	Coefficient of Variation
DOI	Digital Object Identifier
FAO	Food and Agriculture Organization of the United Nations
FCI	Fixed Capital Investment
GDP	Gross Domestic Product

GIS	Geographical Information System
GRAS	Generally Recognized as Safe
GTIP	Gümrük Tarife İstatistik Pozisyonu (Customs Tariff Statistics Position)
HI	Harvest Index
HS	Harmonized System (International Customs Code)
I–O	Input–Output
ITC	International Trade Centre
KW	Keywords
K-S	Kolmogorov–Smirnov
MAE	Microwave-Assisted Extraction
MAM	Marmara Research Center (TÜBİTAK-MAM)
MCDM	Multi-Criteria Decision Making
PDF	Probability Distribution Function
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
p-value	Probability Value
RPR	Residue-to-Product Ratio
ROI	Return on Investment
SFE	Supercritical Fluid Extraction
SC–CO_2	Supercritical Carbon Dioxide
SWE	Subcritical Water Extraction
S-W	Shapiro–Wilk
TAGEM	General Directorate of Agricultural Research and Policies (Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü)
TI	Title
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TUIK	Turkish Statistical Institute (Türkiye İstatistik Kurumu)
TÜBİTAK	The Scientific and Technological Research Council of Türkiye (Türkiye Bilimsel ve Teknolojik Araştırma Kurumu)
UAE	Ultrasound-Assisted Extraction

CHAPTER 1

INTRODUCTION

A growing world population and expectations for improved quality of life are increasing pressure on food and raw material production, rapidly expanding both the volume and diversity of agricultural activities (Bozerup, 1975). Agricultural production processes encompass fundamental stages such as crop cultivation, harvesting, processing, and marketing. At the same time, a significant amount of by-products and waste is naturally generated as an outcome of these processes. These outputs, considered to have little economic value and generally of secondary importance, are classified as "agricultural waste" (AW) despite the costs associated with collection, transportation, storage, and processing (Maji et al., 2020).

In the last century, rapid population growth and agricultural growth, particularly in China, India, and Africa, have led to a significant increase in AW volumes globally (Koul et al., 2021). This increase is expected to accelerate as agriculture continues to expand in developing countries. This situation increases the importance of circular economy practices such as the recovery, recycling, and reuse of AW. This demonstrates that analyzing the source, quantity, and composition of waste is a strategic necessity for effective agricultural waste management (AWM). Türkiye, with its agroecological diversity, diverse climate zones, and rich plant production patterns, is one of the world's leading agricultural countries (Sarı, 2022). This production potential generates a high volume of AW, not only in terms of primary products but also in terms of field and agro-industrial waste. While these wastes originating from agricultural production processes have been considered low-value by-products for many years, the strengthening of bioeconomy, biochemistry, and green transformation policies has made it clearer that they have the potential to be transformed into high-value-added inputs (Eraktan, 2011; Sarı, 2022).

The increasing need for natural resources, in sectors such as food, cosmetics, pharmaceuticals, and biotechnology, makes it possible to repurpose AW into bioactive compounds, biofuels, compost, feed, or biomaterials. In this respect, AWs should not only be considered an environmental burden but also a strategic economic resource. Indeed, studies conducted in Türkiye demonstrate the recycling potential of waste from various products at the provincial, regional, and national levels, and offer suggestions for their use in various fields, particularly energy production. These studies, which focus specifically on biofuel and biomass-based solid fuel production, have generally been shaped within the context of Türkiye's high energy import dependency and renewable energy targets (Adıgüzel, 2013; Melikoğlu, 2011; Özütemiz, 2017; Fidan & Alkan, 2014; Çolakoğlu, 2018). However, this approach has a significant limitation: it fails to evaluate the high-value-added biochemical contents of AWs adequately. Considering AWs solely from an energy production perspective overlooks the economic and strategic value of the functional and bioactive compounds that can be obtained from these sources.

The term bioactive compounds, first coined by Stephen DeFelice in 1979, refers to compounds that prevent, treat, or improve human health (Biesalski et al., 2009; Taşkıran et al., 2023). The literature defines bioactive compounds as natural compounds that have physiological, pharmacological, or nutritional effects on living organisms (Biesalski et al., 2009; Guaadaoui et al., 2014). Compounds found in biological systems are divided into two main classes: primary and secondary metabolites. Primary metabolites, such as carbohydrates, amino acids, proteins, nucleic acids, and fatty acids, are essential for growth, energy production, and the maintenance of cellular functions. In contrast, secondary metabolites, although not directly involved in vital processes, contribute to organisms' adaptation to environmental stress, defense mechanisms, and ecological competitiveness (Azmir et al., 2013; Taşkıran et al., 2023). Among these secondary metabolites, bioactive compounds such as carotenoids, phenolic acids, flavonoids, and phytosterols are of particular interest due to their high economic and strategic value.

Although bioactive compounds can be produced synthetically, there are concerns regarding the long-term health and environmental impacts of these methods. The potential carcinogenic effects of artificial antioxidants, synthetic food additives, and certain pharmaceutical compounds are frequently discussed in the literature and are associated with metabolic disorders such as increased reactive oxygen species (Nieto et al., 2023; Verep et al., 2023). Furthermore, the toxic effects of heavy metal-based additives used in industrial applications pose serious risks to human and environmental health (Ong et al., 2021). For these reasons, many sectors are moving away from synthetic ingredients and instead turning to natural bioactive compounds derived from plants, microbial sources, and especially AWs. The growing popularity of products such as functional foods, natural cosmetics, and herbal medicines is further accelerating this transformation.

At this point, technologies such as Supercritical Fluid Extraction (SFE), which enable the efficient, selective, and environmentally friendly recovery of natural ingredients, have become an indispensable part of sustainable production strategies. SFE is an innovative technique that employs fluids in a supercritical state, achieved under specific temperature and pressure conditions, as solvents (Sapkale et al., 2010). In this state, supercritical fluids combine gas-like diffusivity, which ensures rapid mass transfer, with liquid-like solvation capacity, which allows the dissolution of a wide range of compounds. These unique properties enable supercritical fluids to penetrate porous matrices efficiently and extract target molecules with high yield. Among them, carbon dioxide (CO_2) is the most commonly used due to its non-toxic nature, low critical temperature and pressure, and the absence of solvent residues in the final product (Yener, 2000; Temelli et al., 2012).

Compared to conventional solvent-based extraction methods such as Soxhlet extraction, maceration, and hydrodistillation, SFE offers a more sustainable and efficient alternative (Sapkale et al., 2010; Ahmad et al., 2019; Santana et al., 2024). Traditional methods generally require large volumes of organic solvents, long extraction durations, and high operating temperatures, which can lead to significant solvent waste and the degradation of thermolabile compounds. In contrast, SFE minimizes solvent use, operates under milder thermal conditions, and preserves bioactivity while providing high selectivity—the ability to fine-tune temperature and pressure so that specific bioactive molecules (e.g., carotenoids, polyphenols, sterols) are preferentially extracted while undesired compounds are avoided (Freitas et al., 2021; Rifna et al., 2021).

SFE also presents advantages over other environmentally friendly extraction methods. Microwave-Assisted Extraction (MAE) accelerates solvent heating and matrix disruption using microwave energy, while Ultrasound-Assisted Extraction (UAE) employs ultrasonic waves to enhance cell wall disruption and mass transfer. Subcritical Water Extraction (SWE), on the other hand, utilizes water kept in liquid form at 100–374 °C under high pressure to extract polar compounds (Freitas et al., 2021; Rifna et al., 2021). Although MAE and UAE offer high processing speed and efficiency, they are often limited in selectivity and require considerable energy input. SWE provides an alternative but poses risks of thermal degradation of unstable compounds due to its elevated operating conditions. By contrast, SFE combines moderate temperatures and pressures with superior selectivity and low solvent consumption, positioning it as one of the most sustainable and versatile options for the extraction of heat-sensitive bioactive compounds (Freitas et al., 2021; Rifna et al., 2021; Jha & Sit, 2021).

This study aims to evaluate field and agro-industrial wastes originating from agricultural production processes in Türkiye, with a particular focus on revealing the quantity and potential economic value of bioactive compounds that can be obtained from these residues through SFE. Additionally, it aims to examine the broader macroeconomic implications of this production, particularly in the food, cosmetics, and pharmaceutical sectors, which are the primary application areas of natural bioactive compounds. By addressing both technical and economic dimensions, the study contributes to positioning AWs not merely as an environmental burden or an energy resource but as a strategic input for the bioeconomy.

At this point, it is important to note the distinction between the two terms frequently used in the literature. AW generally refers to these outputs from the perspective of environmental management, disposal challenges, and associated costs. In contrast, Agricultural Residue (AR) emphasises the same materials as potential resources or raw inputs for valorisation, particularly in industrial and economic contexts. Within the scope of this thesis, both terms are acknowledged. However, the analytical focus is on treating AW not only as waste to be managed, but also as AR—an industrially recoverable resource with high value-added potential.

In defining its scope, this thesis focuses exclusively on plant-origin residues that are generated domestically in Türkiye and that hold industrial recovery potential. Two main categories of residues are considered: (i) field residues, including stalks, straw, branches, pruning residues, husks, and leaves left in the field after harvest; and (ii) agro-industrial residues, such as shells, seeds, pomace, peels, and bran generated as by-products of post-harvest processing activities. By contrast, wastes derived from imported products, animal production (e.g., manure, dairy residues), aquaculture, and household/domestic consumption are excluded, as they fall outside the technical and economic boundaries of this research. This clear boundary ensures that the analysis focuses on residues that can realistically be valorized within Türkiye's agricultural and industrial system.

The methodological framework of this thesis is structured as a multi-stage, data-driven approach that integrates agricultural statistics, literature-based evidence, multi-criteria decision-making, and macroeconomic modeling. First, AR amounts were calculated on a product–residue basis using production data, residue-to-product ratios (RPR), moisture content, and availability factors. At the same time, uncertainty in these parameters was addressed through Monte Carlo simulation. Building on this foundation, a systematic literature review was conducted to map SFE studies, generating product-residue-specific scores based on operating parameters, extraction yields, and identified bioactive compounds. These scores were then combined with residue availability data in a multi-criteria decision framework, where the Analytic Hierarchy Process - Technique for Order Preference by Similarity to Ideal Solution (AHP-TOPSIS) method was applied to prioritize ARs according to criteria such as residue volume, collectability, moisture level, and literature support. Following this prioritization, scenario-based calculations were carried out for selected product–residue pairs to estimate bulk extract and specific bioactive compound production under pessimistic, base, and optimistic conditions. Here, bulk extract refers to the bioactive-rich crude extract obtained through SFE, representing the overall mixture of compounds concentrated from the residue. In contrast, specific bioactive compounds denote identified and quantified individual molecules of particular economic or functional interest (e.g., β-carotene, resveratrol, tocopherols), isolated or reported separately within the bulk extract. Finally, an Input–Output (I-O) analysis was employed to evaluate the macroeconomic implications of large-scale bioactive compound production, quantifying its potential impact on sectoral output, value-added, and employment across the Turkish economy.

Through this framework, this study reveals both the technical feasibility and the economic potential of transforming ARs into bioactive compounds through SFE, thereby addressing a multidimensional gap in the literature. In Türkiye, existing research on AWs has primarily focused on energy recovery pathways, such as biofuel and biomass production, a trend closely linked to the country's high energy import dependency and renewable energy targets. At the same time, the growing global demand for bioactive compounds and their strategic importance in the food, cosmetics, and pharmaceutical sectors have brought this field to an increasingly prominent position in the international literature. However, in the Turkish context, systematic and holistic studies focusing on the potential of ARs for bioactive compound production remain limited. By integrating Monte Carlo simulation for modeling residue quantities under uncertainty, systematic mapping of the SFE literature, multi-criteria prioritization, and I-O analysis for macroeconomic assessment, this thesis contributes to shifting the focus beyond low-value, energy-oriented uses and positions ARs as a strategic, high-value resource for the bioeconomy.

This thesis is organized into seven main sections. **Chapter 1** introduces the purpose, scope, and overall approach of the study. **Chapter 2** presents the literature review on AWs, bioactive compounds, and SFE, examining Türkiye's AW profile, the economic significance of bioactive compounds, and current extraction approaches. **Chapter 3** details the methodological framework, including waste quantification, text mining, scoring methods, multi-criteria decision analysis, and macroeconomic modeling. **Chapter 4** introduces the data sources used in the analysis. **Chapter 5** presents the empirical findings, including Türkiye's AR profile, literature mappings, prioritization results, potential production and income estimates, and macroeconomic impact analyses. **Chapter 6** discusses the findings, interprets the implications, and compares them with the existing literature. Finally, **Chapter 7** concludes the study by summarizing key results and offering policy recommendations for enhancing the valorization of ARs via SFE in Türkiye.

CHAPTER 2

LITERATURE REVIEW

2.1. Agricultural Waste: Definitions & Classifications

According to the United Nations' understanding of AW, the classification of waste varies depending on the understanding of agricultural activities and geographical and cultural conditions (Henriksson et al., 2018). Consequently, the success of AWM approaches relies on the creation of bespoke strategies specific to each country and region, considering the origins and properties of the waste.

AW sources are generally divided into two main groups: field waste and agro-industrial waste. Field waste refers to plant residues, such as roots, stems, and leaves, that are generated as by-products of agricultural activities. These residues can offer benefits, including improved soil quality, increased water retention capacity, enhanced soil nutrient levels, and reduced erosion. However, the excessive accumulation of field waste is predicted to pose challenges to environmental, health, and agricultural sustainability, particularly in terms of soil health (Çerçioğlu, 2011; Koul et al., 2021).

Population growth and technological advances have accelerated the industrialization of agricultural practices, including processing, packaging, storage, and marketing of agricultural products. The by-products generated in these stages are often referred to as agro-industrial wastes. However, definitions vary across the literature: some approaches consider a broader scope, encompassing not only industrial residues but also field residues and food wastes arising from linear agricultural production systems (Ogbu & Okechukwu, 2023). While the uncontrolled disposal of such wastes can cause environmental degradation, greenhouse gas emissions, and health concerns, current bioeconomic perspectives also recognize these residues as potential raw materials. Thus, agro-industrial wastes are increasingly framed both as an environmental challenge and as a valuable resource for sustainable industries such as food, nutraceuticals, pharmaceuticals, and cosmetics (Sadh et al., 2018).

Waste sources can be expanded by including livestock and aquaculture wastes (Koul et al., 2021). Livestock, an integral part of agricultural activities, plays a significant role in food production and agricultural systems. Livestock is a significant source of animal-derived food products, including meat, milk, and eggs, which meet both agricultural and human nutritional needs. Waste generated during livestock farming activities is commonly referred to as animal waste, which is often used as a fertilizer. However, the use of concentrated fertilizers or excessive fertilization practices can lead to soil pollution, deterioration of soil quality, and the emission of odors, carbon monoxide, and ammonia into the air.

Agricultural and animal products not only meet increasing global food demands but also contribute to the growth of aquaculture activities driven by agricultural intensification. Aquaculture activities involve the cultivation of organisms that live in aquatic environments (Henriksson et al., 2018). These activities generate solid wastes, such as fish faeces and leftover feed, as well as dissolved wastes, including water-soluble phosphorus and nitrogen compounds derived from these solid wastes. The accumulation of these wastes in water bodies can have negative impacts on aquatic ecosystems, leading to risks such as water turbidity and eutrophication, characterized by excessive algae growth.

Türkiye has a long agricultural history thanks to its rich biodiversity, favorable climate, and geographical conditions. It also boasts a robust agricultural-based industrial structure, enabling it to boast a significant agricultural production capacity. This production process not only produces food and economic value but also generates significant amounts of AW. In the Turkish literature, the concept of AW has been classified and subcategorized by various studies.Ünal and colleagues (2007) examined AW into two main categories. In this classification, the first group includes plant materials such as stalks, straw, and leaves, which remain in the field after harvest, representing waste from crops grown and harvested for nutrition. The second group consists of industrial by-products, such as fruit and vegetable pulp, seeds, and peels, which are defined as waste generated during processing in commercial facilities before being offered to consumers. This classification highlights the two primary sources of AW in the agricultural production cycle.

Öztürk and Baştançelik (2006) adopted a more detailed approach, dividing AW into three main groups. The first group consists of annual crop residues remaining on the field after harvest. This category includes residues from field crops, such as the stalks and straw of cereals like wheat and barley, as well as the cobs and stalks of oilseeds like sunflower and corn. The second group consists of perennial crop residues remaining on the field after pruning trees, husks, and pits. Examples include pruning residues from olive trees, as well as branches and leaves from fruit trees. The third group is referred to as agro-industrial wastes. This category includes fibres from cotton ginning facilities, husks and pulp from seed oil industries, olive pomace from olive oil mills, bran from rice industries, cobs and stalks from corn industries, and grape pomace and pits from wine production. This classification encompasses both field waste and waste from agro-industrial processes, providing a broader perspective on AW.

Tolay (2017) introduced a new dimension to the classification of AWs, dividing them into three main categories. The first category is defined as wastes resulting from plant production. This category includes residues such as stalks, straw, and cobs from field crops, as well as branches and leaves from fruit and vegetable farming. The second category includes wastes resulting from animal production. This group includes animal manures, residues from milk and meat production. The third category consists of wastes generated during the processing of agricultural products. This group includes by-products such as pulp, peels, and seeds resulting from the industrial processing of agricultural products. This classification provides a more comprehensive framework by encompassing both plant and animal production processes, as well as industrial agricultural activities. Sözer (2023) categorizes AW into five main categories: animal manures, organic wastes from cattle and sheep; grain and industrial plant wastes include stalks, straw, and pulp generated after harvesting crops such as wheat, corn, and sunflower; greenhouse wastes are plant wastes resulting from greenhouse-grown crops such as tomatoes and peppers; pruning wastes result from pruning fruit trees such as olives, citrus fruits, and viticulture; and shell fruit and olive oil production wastes include wastes such as hazelnut shells, walnut shells, and olive pomace. This classification details the diversity of wastes resulting from agricultural production and processing processes, including waste from greenhouse production activities within the definition of AW.

As seen in the literature, the definitions and classifications of AWs vary significantly depending on the scope, method, and regional context (Henriksson et al., 2018; Çerçioğlu, 2011; Koul et al., 2021; Ogbu & Okechukwu, 2023; Sadh et al., 2018). While some studies focus solely on plant residues and agro-industrial by-products (Ünal et al., 2007; Öztürk & Baştançelik, 2006), others adopt a broader framework that includes animal manures, greenhouse residues, and even aquaculture wastes (Tolay, 2017; Sözer, 2023). This diversity underscores the need to establish a clear and consistent framework for analysing AW in Turkey. Accordingly, the present thesis adopts a two-stage classification, distinguishing between field waste and agro-industrial waste, taking into account the availability of reliable data and the technical feasibility of recovery. This approach provides a structured basis for examining the potential of utilizing AW through SFE.

2.2. Overview of Agricultural Production and Associated Waste Generation in Türkiye

Since the early days of the Republic, the agricultural sector, one of the pillars of the Turkish economy, has played a crucial role in both feeding the country's population and supplying raw materials for industry (Sarı, 2022). However, the open and free market-based economic policies implemented after 1980 reduced the relative share of the agricultural sector, resulting in a decline in its contribution to employment and national income (Sarı, 2022; Doğan et al., 2015). Despite this, it continues to maintain its strategic importance due to its contributions to the industry, its share in exports, and its role in rural development. Grains, legumes, industrial crops, fruits, and vegetables constitute the primary agricultural production groups in Türkiye.

Grain production is high, led by wheat, barley, and corn. Industrial crops include sugar beets, cotton, and sunflowers. Fruit and vegetable groups such as tomatoes, grapes, olives, apples, and citrus fruits play a significant role in food processing and agro-industrial production (Eraktan, 2011; Sarı, 2022; Akbay et al., 2005).

Türkiye's rich cropping pattern generates significant amounts of field and agro-industrial waste during the production process. Wastes such as cotton stalks, corn cobs, sunflower heads, pruning branches, seeds, pulp, peels, and pulp are generated in significant quantities both at the field level and in the processing industry. The type and amount of AW vary depending on production volume, processing rate, and product characteristics. Furthermore, the strength of agricultural industry integration and the state of infrastructure also determine whether these wastes can be utilized economically.

Indeed, it is known that Türkiye's agriculture-based industries are mainly dependent on agricultural raw materials. Every development in these sectors impacts agricultural production patterns, which indirectly leads to a transformation of the waste profile (Eraktan, 2011). For example, with the increase in fruit juice production, wastes such as citrus peels and apple pulp are becoming increasingly important. Meanwhile, the pomace generated by olive oil production can be utilized as animal feed or as a raw material for energy production.

Therefore, Türkiye's agricultural production capacity indicates a significant resource wealth not only in terms of final product quantities but also in terms of the potential waste generated by this production. AWs are often considered by-products with low economic value; however, the increasing adoption of circular economy and biochemistry-focused approaches reveals the potential for transforming these wastes into valuable inputs (Eraktan, 2011; Sarı, 2022). In this respect, the AW profile should be addressed not only as an environmental issue but also as a strategic economic input.

Studies on AW profiles in Türkiye have been conducted across different provinces, regions, and product groups, providing assessments of field waste and agro-industrial waste at various scales. These studies contribute to the systematic determination of waste quantities, product diversity, and waste types at both national and regional levels.

One of the most comprehensive national-scale studies was conducted by Düzce University, which utilized data from the General Directorate of Energy Affairs' BEPA Biomass Energy Potential Atlas (BEPA) to calculate AW volumes for 81 provinces across seven geographical regions in Türkiye. The study only considered field waste. Accordingly, Türkiye's total vegetal waste volume is estimated at approximately 62.2 million tons/year, of which 46.3 million tons originate from field crops, 11.9 million tons from vegetables, and 4 million tons from horticultural crops. The highest waste-generating crops include wheat (20 million tons), corn (6.8 million tons), barley (5.6 million tons), sunflower (4.5 million tons), cotton (2.8 million tons), hazelnuts (1.1 million tons), grapes (1.7 million tons), tomatoes (4.0 million tons), cucumbers (1.8 million tons), and watermelon (1.2 million tons) (BEPA, 2021; Ünlü et al., 2023).

Another important study covering Türkiye estimated the annual amount of AW nationwide to be approximately 54 million tons. In this study, waste amounts were calculated based on field crops, including wheat, barley, corn, sunflower, and cotton. The key indicators used in calculating waste amounts were compiled from the literature (Avcıoğlu et al., 2019).

Another study comparing the AW profile in Türkiye between 2001 and 2018 revealed that the amount of AW increased in parallel with the rise in production volume, utilizing crops such as wheat, barley, corn, cotton, sunflowers, and sugar beets. These calculations showed that 57 million tons of AW were generated in 2018 (Polat, 2021).

Bahadıroğlu et al. (2022) presented a detailed analysis covering 81 provinces across Türkiye, dividing AW into two groups: primary (PR) and secondary (SR). PR includes residues such as stalks, straw, and stems left in the field after harvest, while SR includes shells, seeds, and pulp resulting from industrial processing of the products. The study included PR sources, such as wheat straw, corn stalks, sunflower hulls, and cotton stalks, as well as SR sources, including almond shells, corn cobs, hazelnut shells, olive pulp, and wheat bran. In total, 39.4 million tons of PR and 6.8 million tons of SR are produced annually in Türkiye.

Ünal et al. (2007) presented a comprehensive analysis of AW, considering product-based production quantities and industrial processing rates across Türkiye. According to the study, approximately 43 million tons of field waste (e.g., straw, stems, and leaves) are generated annually, and around 33%, or approximately 14 million tons, cannot be economically utilized. In addition, approximately 1.4 million tons of agro-industrial waste originating from oil production, fruit and vegetable processing, and other industrial processes comprises products such as grapes, olives, tomatoes, and nuts.

A regional study focuses on the Southeastern Anatolia Project (GAP) Region. In this study, waste types such as straw, sömek, and gin waste from field crops such as wheat, barley, corn, and cotton were evaluated in the provinces of Adıyaman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa, and Şırnak, calculating a total of 5.57 million tons of usable AW (Mutlu et al., 2020).

A study conducted in the Aegean Region evaluated agro-industrial waste in detail and examined its potential on a sectoral basis. The study analyzed data from 925 companies operating in nine different sectors, including olive oil, canned fruit and vegetables, cottonseed, sesame, seafood, tobacco, malt, and paper products. Only 116 companies produced sufficient waste to be utilized for energy production. The amount of waste generated in these sectors varies depending on the product type and process characteristics; for example, the annual solid waste from olive oil production alone was reported to be 510,780 tons. It was noted that agro-industrial by-products such as cottonseed residue, sunflower husks, and sesame pulp are also produced in large quantities and represent a significant biomass potential. In the study, waste amounts were presented both by product (e.g., kg waste/kg raw material) and as total annual tonnage, providing a comprehensive basis for the region's agro-industrial waste profile (Akdeniz et al., 2002).

Two separate studies conducted for Adana and Hatay provinces also detailed the amounts of product-based waste. The Adana study identified a total of 1.88 million tons of AW from crops such as wheat, barley, corn, cotton, and citrus, and reported that the waste originated from both field and agro-industrial sources. The Hatay study calculated the total waste amount as 1.5 million tons. Both studies included RPR coefficients and usability rates in the calculations. In the analysis explicitly conducted for Kayseri province, the total waste amount was determined to be 1.7 million tons; It has been emphasized that 91% of this amount consists of field crops, 6% of vegetables, and 3% of horticultural crops (Karaca, 2019; Karaca, 2019; Karaca, 2024).

A study conducted specifically in Tekirdağ province assessed the amount of field waste generated from wheat, barley, rye, sunflower, corn, rice, oats, and triticale. Calculations based on 2019 production data indicated that approximately 0.7 million tons of waste were usable (Diken & Kayişoğlu, 2020).

A theoretical analysis conducted in Tokat province, taking into account 2019 agricultural production data, examined the amount of waste from plant production in two main categories: field crops and fruit trees. In the study, crops such as wheat, barley, corn, sunflower, and sugar beet were classified as field crops, while apples, pears, cherries, sour cherries, peaches, walnuts, hazelnuts, almonds, and plums were classified as fruit trees. Theoretical waste amounts were determined by multiplying product-based production quantities by waste coefficients, and then technically usable waste amounts were calculated by applying collectability ratios. Accordingly, it was determined that approximately 993,528 tons of usable plant waste were generated annually in Tokat Province from field crop production, and approximately 7,845,125 tons from fruit tree pruning, totalling approximately 8,838,653 tons/year (Baran & Küçüker, 2021).

In a study conducted specifically in Konya Province, plant-based waste generated from agricultural production activities was classified mainly into four categories: grain and field crops, vegetable and fruit residues, fruit tree pruning residues, and greenhouse production waste. The study calculated the collectability potential of these wastes. Accordingly, it has been calculated that approximately 2.1 million tons of technically collectable AW are generated annually from grain and field crop production, 133,210 tons from fruit and vegetable production, 32,276 tons from fruit tree pruning, and 2,911 tons from greenhouse production (Tunçez & Soylu, 2022).

These studies demonstrate that Turkey's agricultural production capacity is a determining factor not only in the supply of food and industrial raw materials but also in the production of significant amounts of AW. Both field waste and agro-industrial waste across the country hold a potential of millions of tons, and these amounts vary depending on region, product group, and processing scale. Considering calculations in the literature, studies focusing solely on field waste estimate an average of 40–60 million tons of AW annually in Turkey (BEPA, 2021; Ünlü et al., 2023; Avcıoğlu et al., 2019; Polat, 2021; Bahadıroğlu et al., 2022; Ünal et al., 2007). A significant portion of this waste is still underutilized, presenting a significant opportunity for the development of sustainable waste management strategies and the conversion of waste into value-added products such as biofuels, biochemicals, or bioactive compounds.

2.3. Quantification Approaches for Agricultural Waste

Approaches to calculating AW quantities are generally classified into two groups: deterministic methods and simulation-based methods that consider uncertainties. Deterministic methods utilize mathematical formulas based on parameters such as production volume, product-to-residue ratio, moisture content, and collectability coefficient to provide direct estimates. However, these methods ignore the variability and uncertainty inherent in these parameters. Therefore, in recent years, simulation-based approaches that account for parameter uncertainties have been developed and are yielding more realistic results. This section provides a detailed discussion of both approaches.

2.3.1. Mathematical Formulation-Based Deterministic Estimation Methods

This section provides an overview of deterministic approaches that aim to estimate agricultural residue quantities using predefined mathematical relationships, offering a structured way to link production data with residue generation through straightforward calculations.

2.3.1.1 Field Residue

Methods for calculating the amount of field waste are generally developed based on production data for the relevant agricultural product. Such production-based approaches aim to estimate waste quantities using primary production data obtained directly or indirectly. Direct primary production data represent the total amount of production for a product. In contrast, indirect primary production data are obtained by multiplying the crop yield by the area of cultivated land or the number of trees (FAO, 2020). In this case, when production amounts are not directly given, calculation formulas such as the following are used:

$$PROD_i = CA_i \; x \; y_{i,area}$$

or

$$PROD_i = NT_i \; x \; y_{i,tree}$$

where

PROD: Production (ton), CA: Cultivated Area (ha), NT: Number of Tree, y_{area}*: Yield (ton/ha),* y_{tree}*: Yield (ton/tree), i: Product*

Cultivated area data is used for annual crops (e.g., wheat, corn, sunflower), while tree count data is used for perennial fruit trees (e.g., apple, olive, hazelnut).

In production-based calculations, the amount of waste generated from the production of a specific agricultural product is estimated using coefficients such as the RPR or the Harvest Index (HI). However, these two concepts evaluate waste amounts from different perspectives. RPR represents the ratio of the amount of by-products or waste generated during the harvest or processing of an agricultural product to the amount of the main product. HI, on the other hand, represents the percentage of the harvested economic portion of a plant's total biomass (Bentsen et al., 2014). In summary, the RPR method is more suitable for determining the amounts of AW, while the HI method is more suitable for analyzing the efficiency of agricultural production systems. Therefore, the basic calculation formula commonly used to calculate the amounts of waste generated by different agricultural products is as follows:

$$AW_{i,field} = PROD_i \; x \; RPR_{i,field}$$

where

AW: Agricultural Waste (ton), PROD: Production (ton), RPR: Residue to Product Ratio, i: Product

RPR represents the amount of by-product or waste corresponding to the harvested portion of a crop. RPR values are generally calculated based on average global or national data. However, this value is not a fixed measure. It can vary depending on regional factors such as climatic conditions, soil fertility, agricultural methods, harvesting techniques, and the use of agricultural machinery. Therefore, both literature-based and field-based approaches are used in determining RPR values.

Many studies calculate RPR values based on average values obtained from national and international literature. For example, Öztürk and Baştançelik (2006) used global RPR values from the 1999 International Commission of Agricultural and Biosystems Engineering (CIGR) book to calculate AW quantities. Similarly, Baran and Küçüker (2021) utilized 2015 California Energy Commission (CEC) data as a source for analyzing the waste potential of agricultural products in Tokat Province. While these literature-based approaches enable the direct adaptation of global RPR values to Turkish conditions, they may limit consideration of regional conditions.

In this context, one of the most comprehensive studies aimed at determining the potential for agricultural production and waste in Türkiye is the BEPA project. This study, prepared by the General Directorate of Energy Affairs (EİGM), an affiliate of the Ministry of Energy and Natural Resources of the Republic of Türkiye, was conducted using a Geographic Information System (GIS)-based approach. BEPA calculates the quantities of agricultural, animal, forest, and municipal waste at the provincial and district levels, revealing the theoretical energy potential of these wastes (BEPA, 2021).

Within the scope of plant production, an assessment was conducted across three groups: field crops, horticultural crops, and vegetable crops. Production data and waste quantities for these groups were detailed. RPR values corresponding to production volume were used in the calculations, and these ratios provided an estimated waste amount for each product. This approach is widely accepted in the literature.

Some studies, based on BEPA data (e.g., Ünlü et al., 2023; Bahadıroğlu et al., 2022), analyzed the most waste-producing crops and their energy potential at the provincial level. However, because the study's methodology was not publicly disclosed, it is unclear whether the production data used fully aligned with those of Turkish Statistical Institute (TUIK). Furthermore, BEPA covers only field waste, focusing on the biomass remaining in the field after harvest. The type of waste (e.g., straw or hay) is not specified, which can lead to RPR uncertainty for some crops.

Some studies have adopted direct field data collection to determine RPR values. Ünal and Alibaş (2007) conducted an analysis based on farmer surveys and data obtained from provincial/district agricultural offices to calculate the waste potential of crops across Türkiye. Karaca (2019) utilized RPR values obtained from surveys conducted in each province to estimate the amounts of AW. These methods provide more realistic estimates by taking into account regional differences.

Finally, some approaches combine both literature-based and experimental methods in determining RPR values. For example, Avcıoğlu et al. (2019) analyzed the potential of agricultural biomass in Türkiye by combining data from 16 studies from different countries and adapting these data to Türkiye's specific agricultural conditions. Similarly, Karaca (2019) supplemented literature data with field studies to calculate AW in Adana province.

While RPR is a fundamental criterion for calculating theoretical AW quantities, factors such as usability rates must also be considered for the realistic application of this value (Bahadıroğlu et al., 2022; Karaca et al., 2024). For example, some waste may need to be left in the soil to maintain soil fertility, while other materials may be left to decompose in the soil because they are not suitable for collection. Additionally, land structure, logistical possibilities, and farmers' waste collection tendencies play a critical role in determining the usable amount of waste in a region (Sözer, 2023). Waste collectability rates can be found in studies published in the literature (Ünal & Alibaş, 2007; Sümer et al., 2016; Karabaş, 2019; Karaca, 2019). These rates are consistent with data published by the CEC in 2015 and are generally reported as fixed values. When usability rates are included in AW quantity calculations, the following formula emerges, as also applied in previous studies (Ünal & Alibaş, 2007; Sümer et al., 2016; Karaca, 2019; Bahadıroğlu et al., 2022).

$$AAW_{i,field} = PROD_i \ x \ RPR_{i,field} \ x \ AVAIL_{i,field}$$

where

AAW: Available Agricultural Waste (ton), PROD: Production (ton), RPR: Residue to Product Ratio, AVAIL: Availability of residue, i: Product

While RPR and usability rates are important criteria in calculating AW quantities, the moisture content of agricultural products is also taken into consideration (Öztürk & Baştançelik, 2006; Mutlu et al., 2020; Karaca, 2019). Moisture content is calculated based on the post-harvest weight of the product and the water content of a particular portion of this weight. Studies in the literature generally use moisture content as a correction factor in calculating the actual usable waste amount from the theoretical waste amount. Öztürk and Baştançelik (2006) combined RPR, usability, and moisture content data to calculate Türkiye's potential for biomass energy. Mutlu et al. (2020) used moisture correction for products with high moisture content, such as corn and cotton, when determining AW amounts in the GAP Region. Karaca (2019) analyzed AW specific to Hatay province, evaluating the moisture content while considering the impact of waste on storage and energy conversion processes. Incorporating moisture content into AW quantity calculations yields the following formula, as also applied in previous studies (Öztürk & Baştançelik, 2006; Mutlu et al., 2020; Karaca, 2019).

$$ADAW_{i,field} = PROD_i \ x \ RPR_{i,field} \ x \ AVAIL_{i,field} \ x \ MOIST_{i,field}$$

where

ADAW: Available Dry Agricultural Waste (ton), PROD: Production (ton), RPR: Residue to Product Ratio, AVAIL: Availability of residue, MOIST: Moisture ratio of residue, i: Product

RPR, usability ratio, and moisture content are important interconnected components in calculating AW quantities. Using these factors together enables the assessment of waste quantities and potential, both theoretically and practically applicable. Addressing these parameters with an integrated approach, tailored to Türkiye's regional agricultural structure, will play a critical role in sustainable AW management and achieving economic benefits.

2.3.1.2. Agro-Industrial Residue

Agro-industrial waste is defined as by-products and waste generated during the processing of agricultural products. Calculating these wastes is carried out using a different approach from landfill waste. Generally, quantities of agro-industrial waste are calculated using primary production data, industrial processing rates, and by-product formation coefficients. The industrial processing rate is the ratio of the portion of a given agricultural product directed to the industrial sector to total production. This ratio is used to determine whether agricultural products are intended for direct consumption or are subject to industrial processing. This ratio is particularly widely used in sectors such as fruit and vegetable processing, oil production, grain milling, sugar production, wine production, and the starch and feed industries (Food and Beverage Sector Report, 2022; Northeastern Anatolia Development Agency, 2021; Antalya Provincial Directorate of Agriculture and Forestry, 2023).

The by-product ratio, on the other hand, represents the ratio of the amount of waste or by-product generated during the processing of a given agricultural product to the amount of processed product. This ratio is used to determine the amount of by-products, such as peel, pulp, seeds, and other waste, obtained during the processing process. The processing rate and by-product rate are critical indicators for understanding how AW is utilized in industrial processes.

As a result, the formula used to calculate the amount of agro-industrial waste can be summarized as follows (Ünal et al., 2007; Polat, 2021; Bahadıroğlu et al., 2022).

$$AW_{i,industry} = PROD_i \ x \ IND_i \ x \ PR_{i,industry}$$

where

AW: Agricultural Waste (ton), PROD: Production (ton), IND: Industry Processing Ratio, PR: By-Product Ratio, i: Product

Determining and regularly reporting industrial processing rates is critical for the accurate calculation and effective management of AW. However, the lack of a comprehensive database on this topic in Türkiye limits the management of AW and related policy planning.

Industrial production statistics published by the TUIK provide partial information on the processing of specific products. TUIK's PRODCOM classification provides information on the quantity of products produced by directing agricultural production to industry and the amount of by-products generated during processing. For example, the amount of pulp and other solid residues remaining from soybean oil production is reported. However, this data only includes information on specific products and does not cover all agricultural products. Similarly, plant product balance sheets provide estimated information on the quantities of raw materials used in specific sectors, particularly sugar beet and wine production. However, this data does not fully reveal the total amount of agricultural products processed in industry and the amount of waste generated by each product during processing.

Sector reports provide important information for determining industrial processing rates. The Food and Beverage Sector Report (2022), published by the Ministry of Industry and Technology, indicates that an average of 35-40% of agricultural products in Türkiye are processed industrially. However, this rate varies significantly across product groups. For example, 85-86% of tomatoes are processed for the production of tomato paste, canned food, sauce, ketchup, and puree, while only 8% of potatoes are used for the production of French fries and chips. Sector reports also indicate that the processing rate for some products reaches as high as 100%, with products such as peanuts and olives being fully processed for oil production.

Feasibility reports published under the Investment Support Program provide valuable information for determining processing rates. The Southern Aegean Development Agency (2020) reported that all medicinal and aromatic plants are processed (50% for food, 25% for cosmetics, and 25% for pharmaceuticals). The Northeastern Anatolia Development Agency (2021) assumed that 20% of the fruits produced in Türkiye are used in fruit juice production. The Antalya Provincial Directorate of Agriculture and Forestry (2023) reported that all peanuts are processed for oil production.

Academic studies utilize field studies, sector analyses, and literature data to determine industrial processing rates and by-product ratios. Ünal and Alibaş (2007) reported the processing rates and by-product types for various products, including olives, sunflowers, soybeans, pistachios, almonds, hazelnuts, walnuts, grapes, tomatoes, and rice, in Türkiye through field studies and sector analyses. For example, they reported that 12.4% of olives processed in olive oil production are pits and 15.1% shells. Industrially processed pistachios, almonds, and hazelnuts consist of 60%, 50%, and 53% shells, respectively.

Bahadıroğlu et al. (2022) used by-product ratios reported in the literature, accepting values such as 15% for corn cobs, 50% for sunflower husks, and 13.5% for olive husks. In this study, it was assumed that all grain and shell products should be processed. Bedoic et al. (2019) calculated the amounts of agro-industrial waste in grain, fruit, and vegetable groups using by-product ratios compiled from the literature and reported that 25% of apples constitute pulp, while 13-20% of wheat constitutes bran. Özkan et al. (2023) reported that by-products generated during fruit and vegetable processing generally constitute 20-40% of the main product. In grape processing, pulp accounts for 25% of the total grapes, and the pomace generated during olive processing constitutes 35-40% of the total olives.

These studies demonstrate that industrial processing rates and by-product ratios are a critical data source in AW management and that these ratios can vary regionally. However, the lack of a systematic and comprehensive database specific to Türkiye poses a significant limitation in managing AW. Therefore, a detailed analysis of industrial diversion rates and by-product ratios at the national level would be a crucial step toward more efficient utilization of AW.

While the industrial processing ratio and by-product ratio are fundamental criteria for calculating the theoretical amount of AW, factors such as usability and moisture content must be considered for the realistic application of this value, similar to field waste. The assumption that all agro-industrial waste generated by the processing of agricultural products in industrial facilities is recyclable often loses validity in practice. Such waste can be lost in the processing line or cannot be recovered without being removed from the system, depending on the internal logistics processes of industrial facilities, the adequacy of collection systems, the structure of the production line, and their impact on final product quality. Consequently, a discrepancy exists between the theoretically calculated waste amount and the amount that can be physically collected. Therefore, the collectability rate in the literature is generally accepted as 80%, taking into account technical, logistical, and economic factors (Yücel et al., 2006; Sülük et al., 2018). This rate is based on the assumption that 20% of the waste generated by industrial processing cannot be collected for various reasons. This ratio can be evaluated at lower or higher levels on a product-by-product basis, depending on the recycling capacity and infrastructure level of industrial facilities in Türkiye.

On the other hand, moisture content is critical in waste valuation, particularly for calculations reduced to dry matter. This is because waste with high moisture content cannot be directly utilized for either energy efficiency or economic valuation; drying these wastes has a significant impact on both energy consumption and processing costs. In the literature, moisture content is often classified into three categories: low (5–20%), medium (20–75%), and high (over 75%). This classification creates significant differences in terms of processing technology, drying requirements, and cost analyses (Havlik et al., 2022).

By incorporating usability and moisture content into AW quantity calculations, the following formula emerges, as also applied in previous studies (Öztürk & Baştançelik, 2006; Yücel et al., 2006; Sülük et al., 2018; Mutlu et al., 2020; Karaca, 2019).

$$ADAW_{i,industry} = PROD_i \; x \; IND_i \; x \; PR_{i,industry} \; x \; AVAIL_{i,industry} \; x \; MOIST_{i,industry}$$

where

ADAW: Available Dry Agricultural Waste (ton), PROD: Production (ton), IND: Industry Processing Ratio, PR: By-Product Ratio, i: Product,, AVAIL: Availability of residue, MOIST: Moisture ratio of residue, i: Product

Consequently, industrial processing rate, by-product rate, collectability, and moisture content are complementary fundamental components in calculating quantities of agro-industrial waste. Evaluating these parameters together enables the determination not only of theoretical potential but also of the amount of waste that can be processed under real-world conditions. Considering Türkiye's product-based and regional industrial processing capacity, as well as waste characteristics, addressing these four factors in an integrated manner will both increase resource efficiency in waste management and create a strategic basis for producing high-value-added bioproducts for industry.

2.3.2. Simulation-Based Approaches for Dealing with Parameter Uncertainty

Deterministic approaches, commonly used in estimating AW quantities, are generally based on fixed parameters such as the RPR, moisture content, and collectability coefficient. However, such methods fail to adequately reflect the variability and uncertainty inherent in agricultural production systems. Parameters such as RPR, moisture content, and collectability can vary significantly depending on several factors, including crop type, climate, soil conditions, harvesting techniques, and data source diversity.

To incorporate these uncertainties into calculations, the Monte Carlo simulation has become a widely used approach in recent years to model AW quantities under uncertainty. Monte Carlo simulation analyses the impact of uncertainties in input variables on the results by running simulations based on a large number of random samples, providing probability distributions. This method stands out as an effective tool for analyzing uncertainties, particularly in non-deterministic and complex systems (Metropolis & Ulam, 1949).

Song et al. (2014) generated product-based probability distributions (such as normal, log-normal, and gamma distributions) based on 2123 RPR values obtained from different sources and estimated AW quantities using 2000 iterations of simulations. The resulting data were both statistically evaluated and spatially visualized using GIS. This method offers a significant advantage in analyzing agricultural biomass potential, as it produces reliable prediction intervals in systems with high uncertainty.

Lyakurwa (2016) employed a Monte Carlo simulation to estimate AW quantities with greater accuracy under uncertainty. In the study, RPR data were collected for different crops, and the probability distributions derived from these data were defined as independent variables for each crop in the model. Based on the determined RPR distributions, AW quantities were modelled as forecast variables, and the simulation was run for 2000 iterations. During the simulation process, random sampling was performed using defined probability distributions, and all necessary statistical parameters were achieved by presenting the outputs as histograms. This study demonstrates that the Monte Carlo method stands out for its ability to model natural variability in agricultural systems, providing more realistic results than traditional deterministic approaches.

Maqhuzu et al. (2017) present a probability-based approach to assessing the biofuel potential of ARs and animal manure in Zimbabwe. Considering the uncertainties in agricultural production, 100,000 Monte Carlo simulations were conducted, and biomass quantities and energy potentials were calculated with a wide confidence interval. This method yields more realistic results by incorporating uncertainties overlooked in previous studies, highlighting the need for flexible and versatile technologies in biofuel production.

The relevant literature demonstrates that the limitations of deterministic methods in predicting waste management are increasingly discussed, while Monte Carlo performance emerges as a powerful tool for introducing parameter measurements. Studies by Song et al. (2014), Lyakurwa (2016), and Maqhuzu et al. (2017) demonstrate that these methods yield more reliable and empirical results across different product groups and contexts. These findings demonstrate that incorporating natural variations in production is crucial for a sound and consistent assessment of consumption quantities.

2.4. Recovering, Recycling and Reusing Activities in Türkiye: An Overview of the Literature

The recovery, recycling, and reuse processes of AW are crucial for achieving environmental sustainability and economic benefits (David et al., 2019). Within the scope of recycling activities, biomass energy has been considered a key topic. The conversion of AW into biomass supports various energy production processes, including biodiesel, bioethanol, biogas, biopellets, and activated carbon production. These conversions have the potential to reduce Türkiye's energy imports by reducing its dependency on fossil fuels. Studies by Öztürk and Baştançelik (2006) emphasized Türkiye's significant biomass potential, while Sümer et al. (2016) demonstrated that these resources, when managed appropriately, could contribute significantly to energy production.

Within the scope of recycling practices, studies have been conducted on converting AW into various industrial products, including bioethanol, biodiesel, biogas, and bioplastics. Bioethanol is primarily produced from barley and wheat residues and is considered an alternative to petroleum-based fuels (Adıgüzel, 2013; Melikoğlu, 2011). Although biodiesel production was seen as an opportunity to reduce Türkiye's dependence on oilseed imports, it has not reached the desired level due to infrastructure deficiencies (Özütemiz, 2017; Fidan & Alkan, 2014). Similarly, biogas production was thought to reduce Türkiye's dependence on imports for electricity and heat. However, the desired level has not been reached due to the lack of necessary infrastructure (Özütemiz, 2017; Çolakoğlu, 2018).

Bioplastic production is gaining increasing importance through the use of cellulose and starch derivatives from AWs to reduce the environmental impact of petroleum-based plastics (Bahçegül, 2011; Çolakoğlu, 2018; Köksal et al., 2019). Within the scope of AW recycling, there are also studies on the production of biopellets, biosorbents, activated carbon, construction materials, composite materials, and the production of carbohydrates, fats, proteins, and bioactive compounds in the food sector (Küsek et al., 2015; Doğan, 2005; Akırmak, 2010; Öngören & Sessiz, 2022; Esin & Yüksek, 2008; Demir & Elmalı, 2020; Arslan et al., 2008; Mengeloğlu & Alma, 2002; Çolakoğlu, 2018; Özkan et al., 2023).

Reusing practices, particularly the direct use of AW for animal feed, compost, mulch, and mushroom production, are prominent. Compost, in particular, is seen as a practice that supports agricultural productivity by increasing the low organic matter content of soils in Türkiye (TEMA, 2018; Yıldız et al., 2009). Animal feed production enables the use of nutritious ARs as a food source for farm animals (Akram & Fırıncıoğlu, 2019).

In Turkey, the majority of studies on the utilization of AW focus on energy-related areas. These studies have generally focused on biofuel production (biodiesel, bioethanol) and biomass-based solid fuel production (biobriquettes, biopellets) (Öztürk & Baştançelik, 2006; Sümer et al., 2016; Özütemiz, 2017; Çolakoğlu, 2018). This is directly related to Turkey's high energy import dependency, the increasing demand for renewable energy, and the applicability of biomass energy technologies. However, utilizing AW solely for energy production overlooks the broader potential of these resources. Therefore, studies on converting AW into various industrial products, in addition to energy, are of strategic importance for the circular economy.

2.5. Bioactive Compounds: Definition, Sources, Applications, and Production Methods

The term "bioactive compounds," first coined by Stephen DeFelice in 1979, refers to compounds that prevent, treat, or improve human health (Biesalski et al., 2009; Taşkıran et al., 2023). The literature defines bioactive compounds as natural compounds that have physiological, pharmacological, or nutritional effects on living organisms (Biesalski et al., 2009; Guaadaoui et al., 2014).

Compounds found in biological systems are divided into two main classes: primary and secondary metabolites. Primary metabolites are vital for the basic vital functions of organisms and are found in all living things. Compounds such as carbohydrates, amino acids, proteins, nucleic acids, and fatty acids are essential for growth, energy production, and the maintenance of cellular functions. These compounds are often produced in large quantities and are crucial for the organism's survival. On the other hand, secondary metabolites do not play a direct role in vital processes but are important for organisms' adaptation to environmental factors, strengthening defense mechanisms, and providing a competitive advantage (Azmir et al., 2013; Taşkıran et al., 2023).

Plants and animals differ in their metabolic strategies (Güven & Gürsul, 2014). As non-motile organisms, plants primarily focus on producing secondary metabolites to protect themselves against environmental stressors and pathogens (Uyar & Sürücüoğlu, 2010; Guaadaoui et al., 2014). These compounds are divided into different subgroups, such as flavonoids, polyphenols, carotenoids, phytosterols, and alkaloids. Thanks to their potent antioxidant properties, flavonoids and polyphenols reduce cell damage by neutralizing free radicals, thereby exhibiting anti-inflammatory and antimicrobial effects. Carotenoids are particularly notable for their cardioprotective properties, which support eye and cardiovascular health. Phytosterols have a positive effect on heart health by contributing to the regulation of cholesterol levels. Alkaloids, on the other hand, are medically important for their antimicrobial and pharmacological effects. Therefore, these compounds play a critical role not only in protecting plants against environmental stressors but also in supporting human health (Biesalski et al., 2009; Uyar & Sürücüoğlu, 2010; Karadağ et al., 2022). These compounds are found in a variety of plant sources, such as fruits, vegetables, grains, spices, herbs, and tea (Guaadaoui et al., 2014).

In contrast, animal organisms primarily base their metabolism on primary metabolites. Because animals can escape environmental threats thanks to their mobility, they do not possess as wide a variety of secondary metabolites as plants. Instead, they focus on essential biological processes, such as energy production, tissue repair, and growth, utilizing primary metabolites like proteins, lipids, and nucleic acids (Guaadaoui et al., 2014). Animal-derived bioactive compounds include collagen peptides, conjugated linoleic acid, and biologically active proteins (Taşkıran et al., 2023). Similarly, marine-derived bioactive compounds include biomolecules derived primarily from microalgae, seaweed, and shellfish, including omega-3 fatty acids and astaxanthin (Guaadaoui et al., 2014).

In addition to plant, animal, and microbial sources, AWs are also considered a source of bioactive compounds (Guaadaoui et al., 2014; Bansal et al., 2022; Berenguer et al., 2022). Although agricultural production processes are generally carried out to provide raw materials for food, feed, and industry, a large portion of the wastes generated as a result of these processes are rich in bioactive compounds. AWs; It contains different types of compounds such as phenolics, peptides, polyphenols, tannins, alkaloids, carotenoids, terpenes, flavonoids, flavanols, anthocyanins, essential oils, as well as carbohydrates, enzymes, fatty acids, dietary fibers, lipids, biopolymers, nitrogenous compounds, minerals, vitamins, amino acids, chemicals and other bioactive components (Ben-Othman et al., 2020; Bansal et al., 2022; Berenguer et al., 2022; Yadav et al., 2024). These components are considered health-supporting due to their antioxidant, anti-inflammatory, antimicrobial, cardiovascular protective, and neuroprotective properties. In line with their chemical structures and biological activities, these components are widely utilized in various sectors, including food, pharmaceuticals, cosmetics, agriculture, and biomedical applications (Bansal et al., 2022; Özkan et al., 2023).

Bioactive compounds play a significant role in the development of functional foods and dietary supplements in the food industry. Compounds such as flavonoids, polyphenols, phytosterols, and omega-3 fatty acids are added to food products for their immune-supporting and chronic disease-preventing effects. Polyphenols and natural antioxidants, in particular, are considered food preservatives to extend shelf life by preventing oxidative spoilage (Erbaş, 2006; Bansal et al., 2022). Probiotics and prebiotics are used in dairy products and fermented foods to improve intestinal health. In addition to being added directly to foods, bioactive compounds also serve as preservatives in active packaging systems, extending shelf life (Nieto et al., 2023).

In the pharmaceutical industry, bioactive compounds are widely used in the prevention and treatment of diseases thanks to their pharmacological effects.

Polyphenols and flavonoids protect against cancer, cardiovascular diseases, and neurodegenerative disorders by neutralizing free radicals. Natural ingredients such as curcumin and resveratrol are considered supportive agents in the treatment of many diseases due to their anti-inflammatory and antioxidant properties (Bansal et al., 2022; Uyar & Sürücüoğlu, 2010).

The importance of bioactive ingredients in the cosmetics sector stems from their antioxidant and anti-ageing effects. Vitamin C, vitamin E, carotenoids, and phenolic compounds are widely used in creams, serums, and lotions due to their skin-health-protecting properties. Polyphenols and flavonoids protect the skin against ultraviolet radiations and reduce the signs of ageing by increasing collagen production (Bansal et al., 2022; Rodrigues et al., 2017). The use of these natural ingredients contributes to the development of biocompatible and environmentally friendly cosmetic products by reducing reliance on synthetic chemicals.

In the agricultural sector, bioactive ingredients are used as natural pesticides, biofertilizers, and plant growth regulators. Flavonoids and phenolic compounds are effective in increasing plant resistance to disease and are becoming an integral part of sustainable agricultural practices. In the livestock sector, probiotics, prebiotics, and natural antioxidants are added to animal feeds to support intestinal health and boost immunity (Bansal et al., 2022).

In the biomedical field, bioactive compounds are widely evaluated for their applications in wound healing, tissue engineering, and drug delivery systems. Collagen peptides, chitosan, and biopolymers are utilized in various applications, including biomedical coatings, wound treatment, and tissue regeneration. Furthermore, bioactive compound-based drug delivery systems are being developed to ensure effective drug delivery to target tissues in critical areas such as cancer treatment (Bansal et al., 2022; Bazana et al., 2019).

Bioactive compounds are obtained through extraction. Extraction is a physicochemical separation process that selectively separates and purifies targeted components from a solid or liquid mixture (Taşkıran et al., 2023). This process is based on the solubility of specific components using solvents and is widely applied in many industrial fields, including chemistry, food, pharmaceuticals, cosmetics, and biotechnology (Yener, 2000; Çolak & Tülek, 2003). Extraction can be used to recover valuable components directly from biological materials or industrial by-products. Natural ingredients, particularly those derived from plant and animal-derived raw materials, play a critical role in the production of functional foods, active pharmaceutical ingredients, and cosmetic products (Akbulut & Akbulut, 2024).

Traditional and innovative extraction methods are available for obtaining bioactive compounds. These include maceration, percolation, infusion, decoction, and Soxhlet extraction. While traditional solvent-based extraction methods are widely used, in recent years, innovative extraction methods such as SFE, subcritical water extraction (SWE), ultrasonic extraction (UAE), and microwave-assisted extraction (MAE) have become popular due to environmental concerns and efficiency requirements associated with these methods, which require higher solvent consumption and longer extraction times (Taşkıran et al., 2023; Bitwell et al., 2023).

Innovative extraction methods offer several advantages, including high extraction efficiency, preservation of bioactivity, short extraction times, economic viability, and environmental friendliness (Taşkıran et al., 2023; Jha & Sit, 2021). While these methods share many standard features, they differ in some minor ways. Studies have shown that ultrasonic-assisted and MAEs are more cost-effective than pressurized liquid and SFEs. However, ultrasonic-assisted extraction requires more solvent than other modern methods. SFE, on the other hand, has been found to have difficulties in extracting polar compounds without a co-solvent and has high setup costs (Jha & Sit, 2021; Verep et al., 2023). Consequently, extraction efficiency varies depending on several factors, including the type of solvent used, temperature, pressure, particle size, and interactions between the solvent and the material. Therefore, in industrial and scientific research, selecting the appropriate extraction method is one of the most crucial steps in determining both process efficiency and the functional and chemical properties of the resulting products (Azmir et al., 2013).

Bioactive compounds can be extracted from natural sources or produced synthetically. Synthetic bioactive compounds are compounds produced in a laboratory environment using chemical synthesis or biotechnological methods. These compounds are often used in the pharmaceutical industry, food additives, cosmetics, and biomedical applications (Bansal et al., 2022). Synthetic production enables the production of a specific compound in pure and standardized dosages, and the controlled nature of the production process makes it a more economical solution for large-scale production (Rodrigues et al., 2017). Synthetic production methods have been developed to increase the supply of ingredients derived from natural sources and address sustainability issues. Bioactive compounds, in particular, those that are rare or difficult to produce in large quantities, can be obtained through chemical synthesis or microbial fermentation (Jha & Sit, 2021). Synthetic production reduces the overuse of natural resources and enables the development of more effective formulations for treating certain diseases (Azmir et al., 2013). For example, some antioxidants and polyphenols are synthetically produced and used in the pharmaceutical and food industries. In addition, retinoids and vitamin C derivatives, which are widely used in the cosmetics industry, are among the synthetically produced bioactive ingredients (Bazana et al., 2019).

While synthetic bioactive ingredients offer ease of production and cost advantages, there are ongoing debates about the long-term health effects of these synthetic compounds. Some synthetic food additives, in particular (e.g., BHA, BHT, nitric acid derivatives), have been alleged to have potential carcinogenic effects (Nieto et al., 2023). Furthermore, the use of artificial antioxidants and synthetic drugs has been identified as a significant cause of increases in reactive oxygen species, which contribute to diseases such as cancer and diabetes (Verep et al., 2023). Similarly, synthetic additives are used in coating applications across many industries to enhance coating properties. There are discussions about the potential adverse effects of these substances, which contain heavy metals such as arsenic and chromium with higher atomic weights and densities, on human and environmental health due to their high toxicity (Ong et al., 2021).

These examples illustrate the growing importance of natural alternatives, given the potential health risks and environmental impacts associated with synthetic bioactive ingredients. Today, many sectors are turning to bioactive ingredients of plant and microbial origin instead of synthetic ingredients. The preference for natural ingredients, particularly in functional foods, pharmaceuticals, and cosmetics, plays a critical role in both protecting consumer health and developing sustainable production strategies (Rodrigues et al., 2017; Bazana et al., 2019). The more efficient extraction of plant and microbial bioactive ingredients through the development of extraction technologies stands out as a key factor in this transformation process (Verep et al., 2023).

2.6. Supercritical Fluid Extraction: Definiton, Principals, and Applications

SFE is an innovative extraction method that uses fluids that become supercritical under specific temperature and pressure conditions as solvents (Sapkale et al., 2010). A SFE possesses a unique physical state that combines the high diffusion coefficient of gases with the high solubility capacity of liquids. Thanks to these properties, supercritical fluids can easily penetrate porous structures and dissolve target compounds with high efficiency. CO_2, one of the most widely used supercritical fluids, is preferred because it is non-toxic, operates at low temperatures, and leaves no solvent residue on the extracted components (Yener, 2000; Temelli et al., 2012).

Compared to traditional solvent-based extraction methods such as Soxhlet extraction, maviration, and hydrodistillation, SFE is an environmentally friendly, rapid, and selective method, enabling the preservation of biologically active components while obtaining high-purity products (Sapkale et al., 2010; Ahmad et al., 2019; Santana et al., 2024). Traditional methods generally require large amounts of organic solvents, long extraction times, and high temperatures, which may lead to the degradation of thermolabile compounds and generate significant solvent waste. In contrast, SFE minimizes solvent consumption, operates under milder temperature and pressure conditions, and thus prevents the loss of bioactivity while providing higher selectivity (Fretias et al., 2021; Rifna et al., 2021). Furthermore, SFE has distinct advantages compared to other environmentally friendly extraction methods such as MAE, UAE, and SWE. MAE accelerates extraction by rapidly heating the solvent and plant matrix with microwave energy, while UAE uses ultrasonic waves to disrupt plant cell walls and increase mass transfer (Fretias et al., 2021; Rifna et al., 2021).

SWE, on the other hand, is based on the use of water as a solvent, kept in liquid form at temperatures of 100–374 °C and high pressure. However, the SWE method increases the risk of decomposition of thermally unstable compounds due to high temperatures and pressures (Fretias et al., 2021). In contrast, SFE allows the production of thermally stable compounds at relatively low temperatures and moderate pressures. While MAE and UAE offer high speed and efficiency, they are limited in selectivity and generally require high energy consumption. In contrast, SFE stands out as a more energy-sustainable option with its low solvent consumption (Fretias et al., 2021; Rifna et al., 2021; Jha & Sit, 2021).

An SFE system consists of four main components: a compressor or pump, an extractor, a temperature/pressure control system, and a separator. Various process configurations are possible. Temperature/pressure can be varied to separate the desired extract from the solvent, and absorption or adsorption can be performed under isobaric or isothermal conditions. Furthermore, depending on the polarity of the solutes, the number of compressors or pumps and the temperature/pressure control system can be increased if co-solvents are required. Additionally, multi-stage extraction configurations are possible by increasing the number of separators (Yener, 2000; Çolak & Tülek, 2003). A summary of the multi-stage SFE process using co-solvents is shown in Figure 1 (Özel, 2024; Temelli et al., 2012).

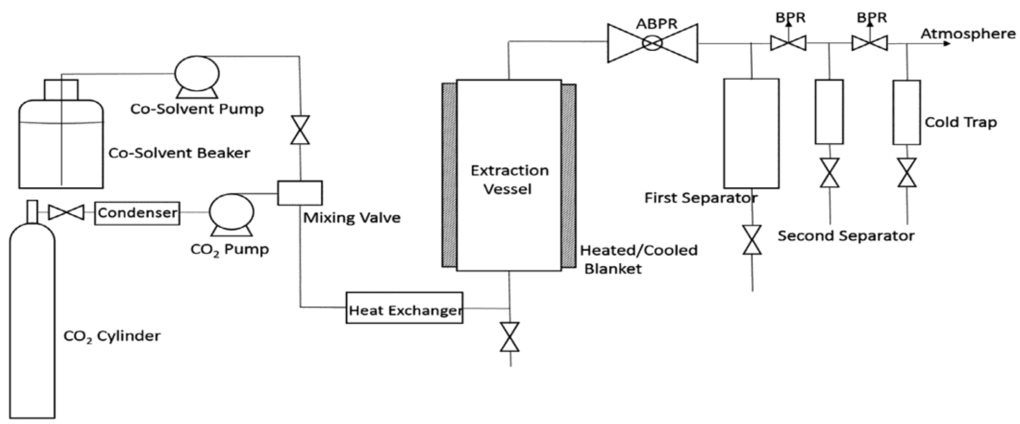

Figure 1. Process Diagram of Multiple Step SFE with Co-Solvent
Source: (Özel, 2024)

To obtain the targeted products using SFE, optimization of extraction pressure, temperature, and fluid flow rate is necessary for effective extraction. For the successful operation of the SFE process, four key points must be known: the solute miscibility zone, the solute fractionation zones, the solute solubility maximum, and the solute physical properties. The solute miscibility zone refers to the temperature and pressure at which solutes dissolve in a supercritical fluid. The solute fractionation zones are the temperature and pressure ranges within which the solubilities of the solutes forming a mixture in the supercritical fluid vary significantly. Within the SFE process, the precise determination of the solute's maximum solubility constitutes a critical parameter in optimizing and enhancing product yield. The physical properties of solutes include their molecular structure and temperature dependence. Solutes can be either polar or nonpolar. In the SFE process, a high degree of polar structure reduces solubility. This necessitates higher pressure and/or temperature in the SFE process, or the inclusion of co-solvents to reduce polar structure (Yener, 2000).

Co-solvents enhance the solubility of polar compounds in the system, allowing the SFE process to operate effectively for these compounds. Ethanol is widely used as a co-solvent in SFE processes. The addition of ethanol increases the polarity of the CO_2 used in the SFE process, improving extraction efficiency and selectivity for target compounds. It was reported to be used as a co-solvent in 53% of comprehensive SFE studies conducted between 2000 and 2013 (Özel, 2024). There are two main reasons for using ethanol in SFE systems. First, ethanol has a high solubility in CO_2. This, combined with the increased polarity of CO_2, facilitates the efficient extraction of highly polar compounds dissolved in SFE. Second, it is considered an environmentally friendly, non-toxic, and biodegradable green solvent (Sezgin & Soyseven, 2022). Additionally, the use of ethanol as a co-solvent in food processing is generally recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) (Ahmad et al., 2019).

Although SFE was described in 1822 by Cagniard de la Tour, it became an industrially applicable technology only in the second half of the 20th century. Research conducted at the Max Planck Institute for Kohlenforschung in the 1970s, in particular, demonstrated the applicability of SFE in the chemical, food, and petroleum industries (Phelps et al., 1996).

The first commercial application of SFE occurred in Germany in 1978 with the decaffeination of coffee. In this process, supercritical CO_2 was used instead of traditional organic solvents, resulting in more environmentally friendly, toxic residue-free, and high-quality products (Yener, 2000). In the 1980s, SFE became increasingly widespread in applications such as hop aroma extraction, tea decaffeination, and the isolation of aroma compounds from spices (Çolak & Tülek, 2003). The industrial adoption of SFE is attributed to the technology's environmentally friendly properties and wide range of applications. The low toxicity, recyclability, and high solubility capacity of supercritical CO_2 (SC-CO_2) make this technology more sustainable compared to traditional solvents. Its large-scale commercial use, particularly in the food industry, for removing caffeine from coffee and tea, has attracted attention (Ahmad et al., 2019). Furthermore, the extraction of essential oils and aroma compounds from plants has enabled the extraction of volatile compounds without degradation, thanks to the low-temperature operation of supercritical CO_2. This feature has enabled the isolation of aroma compounds from plants such as hops, thyme, and rosemary (Freitas et al., 2021).

In addition to the food industry, the pharmaceutical sector is one of the most important applications of SFE. SFE is an effective method for isolating bioactive compounds from plant sources. For example, the sensitive and selective properties of SFE have been utilized in the extraction of flavonoids from Ginkgo biloba leaves, curcumin from turmeric roots, and catechins from green tea leaves (Sapkale et al., 2010). Furthermore, the high-purity extraction of pharmaceutical ingredients, such as steroids and vitamins, has led to the preference for this technology in the pharmaceutical industry (Yener, 2000). In recent years, SFE has also been used in the production of nanoparticles for drug delivery systems, offering innovative solutions for controlled drug release mechanisms (Freitas et al., 2021).

Environmental applications constitute another important application area for SFE. Particularly in the 2000s, the use of SFE has increased in environmentally friendly processes such as the removal of soil and water pollutants, the removal of pesticides, and the production of biodiesel from waste oils (Rifna et al., 2021). SC-CO_2 can be used both as a substitute for toxic solvents and as a selective solution for removing harmful compounds, such as heavy metals. SFE technology is also being applied in the development of sustainable energy sources, such as the recovery of cooking oils and the production of biofuels (Santana et al., 2024).

Polymer and materials engineering is another important application area for SFE. SFE is utilized in various applications, including the removal of solvent residues from polymers, the production of polymer foams used in biomedical devices, and the purification of polymers such as polyolefins (Yener, 2000). SC-CO_2 's low-temperature operation and lack of chemical reactivity offer distinct advantages in polymer processing. Furthermore, the production of microporous foams for medical devices has increased the biomedical uses of polymer materials (Özel, 2024).

Today, SFE is not only an extraction method but also a key tool in green chemistry strategies (Varma & Ghosh, 2020; Amran et al., 2021). This technology lies at the intersection of environmental sustainability, economic value creation, and clean production processes. Since the 2010s, the use of SFE for the valorization of AW and the recovery of bioactive compounds has gained prominence (Freitas et al., 2021; Armenta et al., 2019).

While waste from agricultural production and processing processes generally has low economic value, SFE transforms these byproducts into high-value-added components. By converting AW into valuable components, industrial waste management improves and natural resources are used more efficiently. For these reasons, the importance of SFE in AW management and bioeconomy applications is increasing (Amran et al., 2021; Özkan et al., 2023; Santana et al., 2024).

2.7. Valorization of Agricultural Residues via SFE: A Review of Recent Studies

SFE transforms AW into high-value products, contributing to the goals of reducing waste and reusing existing resources through circular economy and sustainable production strategies. Furthermore, within the framework of the bioeconomy, using agricultural by-products to obtain bioactive compounds contributes to economic development and helps preserve natural resources (Santana et al., 2024).

Numerous studies have demonstrated the effectiveness of SFE in obtaining bioactive compounds from AW. It has been demonstrated that phenolic compounds, essential oils, flavonoids, sterols, tocopherols, and various antioxidant compounds can be obtained from these wastes. These groups offer high added value in various sectors, such as food, cosmetics, and healthcare, thanks to their diverse biological effects, including antioxidant, anticarcinogenic, and cholesterol-lowering properties (Herrero et al., 2010; Azmir et al., 2013; Sagar et al., 2018). Table 1 provides an overview of the main groups of bioactive compounds obtained by the SFE method, the types of ARs from which these compounds are extracted, their application areas, and references to relevant studies. The classification of ARs in this table is based on evidence gathered from the literature.

According to Table 1, citrus peels are waste products rich in valuable components, including essential oils and flavonoids. A study in which orange, tangerine, and lemon peels were subjected to modified SFE with 20% ethanol reported high yields of flavonoids and essential oils (Romano et al., 2022). These compounds are used as flavoring agents in the food industry and as active ingredients in the cosmetics sector. Another study reported that volatile components such as limonene and linalool were extracted from citrus peels with high purity. It was also emphasized that citrus waste is a significant source of antioxidant and antimicrobial compounds (Sagat et al., 2018).

In a study aimed at obtaining phenolic compounds from orange and lemon pulp obtained after fruit juice production using the SC-CO_2 extraction method, the effects of parameters such as extraction time, temperature (40–60 °C), pressure (100–200 bar), and 25% ethanol (v/v) on extraction yield were investigated. A comparison was made with the Soxhlet method, and extract yields of up to 38.2% were obtained from lemon pulp and 38.16% from orange pulp. With the SC-CO_2 method, extract yields of 3.46% were achieved from lemon pulp and 2.784% from orange pulp using a co-solvent. Furthermore, although the total phenolic content, flavonoid content, and antioxidant activity values of the extracts obtained using the SFE method were lower than those obtained using the Soxhlet method, they were noted for their environmental friendliness and lack of solvent residue (Ergüt, 2015).

In a study aimed at obtaining oil from orange peel and apricot pit waste generated after fruit juice production using the SC-CO_2 extraction method, the effects of parameters such as pressure (80-120 bar) and temperature (40-60 °C) on extraction efficiency were investigated. A comparison was made with the Soxhlet method, and it was found that the orange peel extract contained 1% oil, which was lower than that of the Soxhlet method. However, the SC-CO_2 method was reported to be superior in terms of extract quality (Yıkar et al., n.d.).

Carotenoids were extracted from apricot pulp generated during fruit puree production using SC-CO_2. SC-CO_2 extractions were conducted at temperatures between 313–333K and pressures between 30.4–50.7MPa. Experimental results were compared with those obtained from conventional solvent extraction. The highest β-carotene yield (88 µg/g dry pulp) was achieved by adding 4 mL of 2,2-dimethoxypropane (DMP) per 1 g of pulp at 40.5 MPa, 328 K, a CO_2 flow rate of 1 mL/min, and an extraction time of 90 minutes. The SC-CO_2 method achieved similar yields compared to conventional solvent extraction, but at twice the time, with a 31 times lower cost, and with less use of non-toxic solvents. These results demonstrate that the SC-CO_2 method is an environmentally friendly and efficient alternative for obtaining carotenoids from apricot pulp (Şanal et al., 2004).

A study conducted using SC-CO_2, MAE, and conventional extraction methods aimed to increase the d-limonene content of essential oils obtained from orange, lemon, tangerine, and grapefruit peel waste. In extractions performed using the SC-CO_2 method, the highest extract yield was obtained at 45 °C and 200 bar, while the highest D-limonene ratio of 85.43% was obtained at 60 °C and 200 bar. It has been emphasized that SC-CO_2 extraction is particularly effective in terms of D-limonene richness and antioxidant properties; however, parameter optimization plays a crucial role (Yavuz, 2023).

In a study aimed at extracting phenolic compounds from tangerine peels and leaves, SC-CO_2, UAE, and MAE methods were comparatively applied. The study demonstrated that UAE yielded the highest antioxidant yield under optimal extraction conditions; however, SC-CO_2extraction offers an alternative potential for increasing antioxidant capacity (Ateş, 2017). Grape seeds and post-wine pomace are rich in bioactive compounds, including polyphenols, proanthocyanidins, and resveratrol. Barba et al. (2016) investigated the SFE of polyphenols from grape pomace and achieved a yield of over 85% under optimal conditions. This study enabled the evaluation of polyphenols in the food and healthcare sectors while preserving their antioxidant and anticarcinogenic properties.

In a study conducted on the extraction of oil from grape seeds, Soxhlet and SC-CO_2 methods were comparatively evaluated. The study investigated the effects of temperature and pressure changes on extraction efficiency; at 120 bar and 40 °C, the SC-CO_2 method yielded 13% more oil than Soxhlet extraction. This result demonstrates that the SC-CO_2 method is an effective alternative for extracting oil from AWs, such as grape seeds (Yıkar et al., n.d.). In another study examining oil extraction from grape seeds, the use of co-solvents was evaluated due to the low yields obtained. In extractions with ethanol, methanol, and hexane, methanol yielded stable results up to a concentration of 30% and contributed to the recovery of procyanidins. It was observed that extract yield depended more on the use of modifiers than on temperature or pressure. The study demonstrates that high-quality extracts can be obtained from Şenso grape seeds in a short time, and that the SC-CO_2 method holds potential not only for oil extraction but also for the extraction of oligomeric proanthocyanidins (OPCs). In this context, the conversion of grape seed waste generated after wine production into bioavailable products has been reported to be of both environmental and economic importance (Akgün & Akgün, 2006).

Similarly, pomegranate peels and pulp are also important sources of phenolic compounds. A study by Li et al. (2006a) performed SFE extraction of phenolic compounds from pomegranate peels and pulp, and presented comparative analyses. The results of the study revealed that pomegranate peels contain approximately 10 times more phenolic compounds than pomegranate pulp. Pomegranate peel, a valuable AW containing high amounts of ellagitannins, gallic acid, punicalagin, and other phenolic compounds, is considered an important source for the extraction of biologically active components using SFE.

Another study compared SFE applications using different solvents for the extraction of pomegranate peel and seeds (Ko et al., 2021). This study noted significant differences in both yield and component profiles of extracts obtained using solvents such as CO_2 and propane. It was reported that the yield from pomegranate seed oil, particularly in extractions using propane, reached up to 17.12%, and that this oil was rich in functional fatty acids such as punicic acid, oleic acid, and linoleic acid. In SC-CO_2 extractions, oil yields generally ranged from 12% to 15%. However, it was emphasized that this method offers superiority in terms of leaving no solvent residue and preserving the structure of thermolabile components. High levels of polyphenols, ellagic acid, and antioxidant activity were detected in pomegranate peel extracts. These compounds are reported to have potential for use in food supplements, functional beverages, natural cosmetics, and pharmaceutical products.

Tomato waste, especially industrial by-products such as peel and pulp, is a highly suitable raw material for the SFE method due to its lycopene-rich content. The ability to obtain lycopene with high yields and without solvent residue by the SFE method makes this method advantageous compared to traditional extraction techniques. In a comprehensive review by Konar et al. (2012), different SFE studies were evaluated, and their process conditions and extraction yields were compared. Accordingly, SFE generally employs temperatures of 50–110 °C, pressures of 300–400 bar, and extraction times of 0.5–8 hours, with yields ranging from 33% to 100%. The use of co-solvents (especially ethanol or vegetable oils) and sample preparation parameters (drying method, particle size) plays a decisive role in yield. For example, yields ranging from 61% to 93% have been obtained from industrial tomato waste. Studies using co-solvents have reported yields ranging from 54% to 60%. In a study conducted in Türkiye, Baysal et al. (2000) extracted 54% lycopene from tomato paste waste, while Topal et al. (2006) obtained 1.18 mg/g lycopene with a 6.5-hour extraction at 100 °C. These findings demonstrate that tomato waste offers significant potential for both high yields and the production of lycopene with preserved biological activity using the SFE method. Herrero et al. (2010) reached similar conclusions in their study, noting that high temperature and pressure parameters increase the yield of lycopene extraction from tomato peels.

Table 1. Bioactive Compounds Extracted via SFE from AWs

Bioactive Compound Group	Specific Compounds	AW	Sectors	References
Carotenoids	α-Carotene, β-Carotene, Lutein, Lycopene, Zeaxanthin, β-Cryptoxanthin	Carrot peel and pomace, mango peel and kernel, tomato peel and pomace, pumpkin pomace, spinach stalk, red pepper peel, watermelon rind, orange pomace, apricot pomace, broccoli pomace, peach peel	Food, cosmetics, pharmaceutical	Karadağ et al. (2022); Amran et al. (2021); Kainat et al. (2022); de Melo et al. (2014); Afraz et al. (2023); Hashemi et al. (2022); Herrero et al. (2010); Santana et al. (2024); Yadav et al. (2024); Sagar et al. (2018); Baysal et al. (2000); Topal et al. (2006); Dervişoğlu et al. (1996); Rodrigues et al. (2017); Şanal et al. (2004);Yıkar et al. (n.d.)
Phenolic Acids	Hydroxybenzoic acids, Hydroxycinnamic acids, Hydroxyphenylacetic acids, Hydroxyphenylpropanoic acids, Hydroxyphenylpentanoic acids	Apple peel and pomace, pomegranate peel, grape seed, walnut shell, corn cob, banana peel, mango kernel, mango peel, olive peel, potato peel, avocado peel and kernel, rye bran, oat bran, carrot pomace	Food, health, pharmaceutical	Karadağ et al. (2022); Amran et al. (2021); Kainat et al. (2022); Herrero et al. (2010); Afraz et al. (2023); Vigano et al. (2015); Sarangi et al. (2023); Azmir et al. (2013); Guaadaoui et al. (2014); Bansal et al. (2022); Sagar et al. (2018); Fărcaș et al. (2022); Li et al. (2006a); Ko et al. (2021); Rodrigues (2017); Yıkar et al. (n.d.); Akgün & Akgün (2006); Barba et al. (2016); Fărcaș et al. (2022)
Flavonoids	Flavonols, Flavanones, Flavanols, Flavones, Isoflavonoids, Anthocyanins, Chalcones, Dihydrochalcones, Tocopherols	Citrus peel, grape peel, pomegranate pomace, apple pomace, blueberry peel, grape seed, onion peel, olive leaf and pomace, rice bran, wheat bran, chili pepper stalk	Food, health, cosmetics	Karadağ et al. (2022); Amran et al. (2021); Kainat et al. (2022); de Melo et al. (2014); Afraz et al. (2023); Majumder & Annegowda, (2021); Ozkan et al. (2023); Erbaş, (2006); Rodrigues et al. (2017); Sagar et al. (2018); Fărcaș et al. 2022; Rodrigues et al. (2017); Baixinho et al. (2025); Romano et al. (2022); Sagar et al. (2018); Ergüt (2015); Yavuz (2023); Ateş (2017)
Glucosinolates	Isothiocyanates, Thiocyanates, Nitriles, Hydroxynitriles, Epithionitriles	Broccoli stalk, outer cabbage leaves, cauliflower leaves	Food, health	Karadağ et al., 2022; de Melo et al., 2014; Herrero et al. (2010); Zhou et al. (2021); Amran et al. (2021)
Lignans	Acetoxypinoresinol, Hydroxyenterodiol, Secoisolariciresinol	Flaxseed hull, sesame pomace, watermelon rind, tamarind seed	Food, health	Karadağ et al., 2022; Banarjee et al., 2017; Hashemi et al., 2022; Sagar et al., 2018
Organosulfur Compounds	Isothiocyanates, Indoles, Allyl sulfur compounds, Sulforaphane	Garlic peel, onion peel, broccoli stalk, cabbage pomace	Food, health, pharmaceutical	Karadağ et al., 2022; Azmir et al., 2013; de Melo et al., 2014
Phytosterols (Plant Sterols)	Sitosterol, Campesterol, Stigmasterol, Sitostanol, Campestanol, Stigmastenol	Olive pomace, sunflower pomace, grape seed, tomato seed oil press cake, medlar seed, pumpkin seed, citrus peel, peach kernel	Food, health, cosmetics	Karadağ et al. (2022); Amran et al. (2021); Herrero et al. (2010); de Melo et al. (2014); Vigano et al. (2015); Ozkan et al. (2023); Caballero et al. (2019); Le Floch et al. (1998); Hashemi et al. (2022); Şahin (2011); Yıkar et al. (n.d.); Keskinkaya et al. (2023)

The extraction of valuable components from the pulp, consisting of tomato peels and seeds obtained as waste from tomato processing plants in Türkiye, was investigated using the SC-CO_2(SC-CO_2) method. Dried pulp obtained from the Manisa region was separated into peels and seeds, to obtain oil from the tomato seeds and lycopene from the peels. Extraction experiments using SC-CO_2 revealed that oil yield varies depending on pressure, temperature, and solvent flow rate, with higher yields achieved at higher pressures (up to 200 atm). The resulting oils were analyzed using gas chromatography, and fractionation studies demonstrated the selective extraction of clear oils rich in linoleic, oleic, and palmitic acids. Lycopene extraction, however, was not achieved at the desired level due to pressure limitations in the current system. The study demonstrated that high-quality oil production from tomato seeds using SC-$CO_2$is possible and that the fatty acid composition can be transformed into the desired structure through fractionation (Dervişoğlu et al., 1996).

In a study conducted to evaluate tomato processing wastes from TUKAŞ, a company that plays an active role in tomato paste production in Türkiye, the aim was to obtain lycopene and β-carotene from tomato pulp using the SC-CO_2 method. To optimize the extraction process, parameters such as temperature (35–65 °C), pressure (200–300 bar), co-solvent (5–15% ethanol), extraction time (1–3 hours), and CO_2 flow rate (2–8 kg/h) were evaluated. As a result of the study, the highest lycopene yield (53.93%) was obtained with a 2-hour extraction at 55 °C, 300 bar, 4 kg/h CO_2 flow, and 5% ethanol. Similarly, approximately 50% of the β-carotene was extracted at 65 °C, 300 bar, and the same co-solvent and flow conditions. These findings demonstrate that the SC-CO_2 method is an effective method for efficiently recovering carotenoids from tomato processing waste (Baysal et al., 2000).

Olive leaves, pulp, and pits are rich sources of phenolic compounds, and it is possible to obtain these compounds in high purity with SFE. Cabalerro et al. (2019) performed SFE on pruning waste, leaves, and pulp generated during olive production and processing, using 60% ethanol at three different pressures. The results showed that SFE performed at 300 bar was the best option for obtaining high-activity antioxidant extracts from olive waste. In another SFE study for the isolation of phenols from olive leaves, 45% efficiency was achieved using CO_2 modified with

10% methanol (Le Floch et al., 1998). Olive pulp is also rich in phytosterols. Phytosterols are in increasing demand in the food and healthcare sectors due to their cholesterol-lowering effects and protective properties against cardiovascular diseases (de Melo et al., 2014; Hashemi et al., 2022).

Another study on the extraction of oleuropein from olive leaves compared the methods of classical solvent extraction, Soxhlet, and SC-CO_2. The study, conducted using leaves collected from olive trees, analyzed the amount of oleuropein in the extracts. In the SC-CO_2 method, the type and amount of co-solvent were found to affect extraction efficiency significantly. Furthermore, environmental factors such as olive tree species, geographical location, seasonal variability, and water stress were found to affect total phenolic and amino acid concentrations. These findings demonstrate that SC-CO_2 extraction is an effective method for obtaining phenolic compounds (Şahin, 2011). A similar comparative analysis was conducted on oil extraction from olive pomace, a by-product of the olive oil production process (Yıkar et al., n.d.). The study focused on extracting oil from olive pomace, and the oil content in the extracts was analyzed. The study's results showed that although the SC-CO_2 method yielded less oil than Soxhlet extraction, the extract was superior to Soxhlet extraction in terms of quality, appearance, colour, and consistency.

Another study on olive leaves evaluated the phenolic and flavonoid contents, as well as the in vitro antioxidant activities, of two different extracts (obtained at 150 and 300 bar) from leaves collected from wild olive trees using SC-CO_2. The study revealed that wild olive leaves, as natural sources of phenolics and flavonoids, possess strong antioxidant potential and have the potential to be used as food preservatives (Keskinkaya et al., 2023).

The studies in Table 1 demonstrate that the SFE method can be successfully applied not only to ordinary wastes such as tomatoes, grapes, olive pulp, and citrus, but also to other vegetable, fruit, and grain wastes, yielding various bioactive compounds. For example, waste from Brassica species, such as broccoli and cabbage stems, has been reported to yield high levels of isothiocyanates and polyphenols under high pressure (250-350 bar) and moderate temperatures (50-65 °C). These compounds have high potential for use in food supplements and natural cosmetics (de Melo et al., 2014).

Another study by Zhou et al. (2021) demonstrated that isothiocyanates and phenolic compounds can be extracted from vegetable waste with high yields using the SFE method. Broccoli stems, cabbage outer leaves, and cruciferous vegetable wastes were reported to exhibit antioxidant and anticarcinogenic properties. Furthermore, these compounds have demonstrated high potential for use in the food and healthcare sectors. Similarly, Herrero et al. (2010) demonstrated that glucosinolates and organosulfur compounds obtained from vegetable waste have antioxidant and anticancer properties, and that these compounds can be extracted more effectively using SFE at low temperatures and high pressures.

A study by Rodrigues et al. (2017) reported that vegetable wastes such as carrot pulp and red pepper stems are rich in carotenoids and phenolic compounds, and that these compounds can be extracted with 70-85% yield using SFE. Researchers have highlighted the potential for utilizing vegetable waste as functional ingredients in the food and cosmetics industries. Furthermore, some studies have evaluated vegetable wastes, such as carrots, broccoli, and cabbage, using SFE and reported high yields of bioactive compounds, including phenolic compounds, flavonoids, and carotenoids. These compounds have been highlighted as valuable components for the food and cosmetics sectors, with potential for industrial-scale applications (Azmir et al., 2013; de Melo et al., 2014; Amran et al., 2021).

In a study by Fărcaș et al. (2022), cereal wastes such as wheat bran and corn cobs were evaluated for phenolic compounds and tocopherols, and it was reported that they could be extracted with high yields using SFE. The study indicated that SFE enables extraction without leaving solvent residue, preserving the biological activities of bioactive components. Similarly, in a study by Baixinho et al. (2025), an optimization was performed on the SFE of γ-oryzanol and fatty acids from rice bran. In this study, high yields were achieved at a pressure of 500 bar and a temperature of 62 °C. The obtained extracts were reported to exhibit antioxidant and anti-inflammatory properties. These studies demonstrate the effective use of SFE in obtaining high-value bioactive compounds from AW. The increasing demand for natural and sustainable ingredients, particularly in sectors such as food, cosmetics, and healthcare, has accelerated the industrial integration of SFE technology. Pilot and semi-commercial facilities for producing bioactive compounds, such as carotenoids, phenolics, and sterols, from AW have been established worldwide in countries like Germany, Austria, and the United States. In some cases, the extracts have been integrated into commercial products.

Germany-based Flavex Naturextrakte GmbH extracts functional compounds from various plant and food by-products, such as rosemary antioxidant, pepper oleoresin, and tea extracts, using SC-CO_2 for the pharmaceutical and cosmetic industries. Having developed pilot and production-scale extractor systems from 5 L to 100 L, the company ensures the preservation of biological activity under low-temperature conditions and adopts environmentally friendly processes to extract natural ingredients (FLAVEX, 2025; Zhang & Wu, 2025).

Austria-based NATEX designs and manufactures pilot-scale and industrial-scale SFE systems for extracting bioactive compounds from AW and plant-derived raw materials. Offering specialized solutions for the food, cosmetics, and pharmaceutical industries, the company has focused on expanding the application areas of SC-CO_2technology in the 2020s, in line with the European Green Deal and sustainability goals. In this context, it conducts projects not only for the extraction of bioactive compounds but also for applications in high-impact environmental areas, such as the production of valuable chemicals from biomass and the recovery of waste oils (NATEX, 2025).

US-based HighTech Extracts LLC is a company specializing in supercritical and subcritical fluid extraction technologies, offering innovative solutions. It enables the environmentally friendly extraction of bioactive compounds from various biomass sources, including plant materials, food waste, microalgae, and agricultural by-products. The company specializes in the design, installation, and optimization of both pilot- and industrial-scale systems, particularly in the field of SC-CO_2. Application areas include: Its product range includes functional food additives, natural flavorings, cosmetic actives, and pharmaceutical raw materials. HighTech Extracts LLC, distinguished by its advantages such as high purity, solvent-free production, and sustainable product quality, offers process development, engineering support, and specialized extract production solutions to its global customers (HighTech Extracts LLC, 2025).

Similarly, US-based companies such as Phasex Corporation, Eden Labs, NutraGreen Biotechnology, Blue California, D.D. Williamson & Co. and Arista Industries process various AWs to produce bioactive compounds using the SFE method. Phasex Corporation isolates health-beneficial compounds, such as carotenoids and phytochemicals, from sources including plant waste and food residues. These substances are primarily used in dietary supplements and functional products (Phasex, 2025; Zhang & Wu, 2025). Eden Labs, on the other hand, uses SFE to extract antioxidant compounds (e.g., polyphenols and flavonoids) from AWs such as grape skins and tomato pulp. These compounds are incorporated into foods and supplements, reducing the need for additives and providing a natural ingredient (Eden Labs, 2025; Zhang & Wu, 2025).

Companies such as NutraGreen Biotechnology and Blue California are developing natural and functional products by extracting bioactive compounds from agricultural by-products, including rice bran, grape pomace, and citrus peels. These compounds are attracting attention, particularly in the healthcare sector, for their anti-inflammatory and antioxidant effects (Blue California, 2025; Nutra Green, 2025; Zhang & Wu, 2025). D.D. Williamson & Co. (based in the US and under the umbrella of Givaudan, Switzerland) produces natural food colorants using fruit and vegetable waste, contributing to clean-label products. Similarly, Arista Industries produces speciality oils derived from plant waste for use in cosmetics and healthcare (Zhang & Wu, 2025).

India-based Vidya Herbs Pvt. Ltd. utilizes SFE to extract bioactive compounds, including polyphenols and proanthocyanidins, from apple peel and grape seeds. In addition to its central facility in Bangalore, Vidya Herbs opened a new production facility in Florida, USA, in 2023. Vidya Herbs offers natural ingredients for the food supplement, pharmaceutical, and cosmetics sectors. The company's R&D activities aim to develop sustainable and innovative extraction solutions (Vidya Herbs Pvt. Ltd., 2025).

Indena S.p.A., based in Italy, is a global leader in the identification, development, and industrial-scale production of plant active ingredients. Using advanced technology, including SC–CO_2, the company produces polyphenols, flavonoids, phytosterols, and other bioactive ingredients for the pharmaceutical, nutraceutical, and cosmetic sectors in facilities that comply with GMP and ISO standards (Indena S.p.A., 2025). Significant research is underway on an industrial scale to recover valuable components from AW. For example, under its proprietary product, Curbilene®, Cucurbita pepo (pumpkin) seed residues are extracted using SC–CO_2, yielding a functional extract containing over 85% oil and sterols (Indena S.p.A., 2025). Additionally, a study published in the journal Molecules yielded specific sterols and free fatty acids through SC–CO_2 extraction from industrial pumpkin seed waste provided by Indena; these compounds were highlighted as valuable fractions that can be utilized through biocatalysis (Massironi et al., 2022).

Similarly, Exania Group S.R.L. (Italy) is developing both pilot- and industrial-scale SC–CO_2 systems for the extraction of high-value-added bioactive compounds (e.g., essential oils, aroma, and antioxidant compounds) from AW and food by-products (Exania Group, 2025). For example, Exenia's pilot plant in Pinerolo enabled the SC–CO_2 extraction of valuable compounds, such as γ-oryzanol, vitamin E, and essential oils, from agricultural by-products, including rice bran, tomatoes, and grape pomace, under optimized conditions (Garofalo et al., 2023).

These examples demonstrate that companies operating in diverse geographies are successfully utilizing SFE technology to transform AW into high-value-added products. In both the European Union and Asia, as well as North America, waste from the agricultural and food industries is being converted into essential oils, antioxidants, phenolic compounds, and similar bioactive substances, resulting in both economic and environmental benefits. This demonstrates that SFE is positioning itself as a sustainable and environmentally friendly alternative to traditional solvent-based methods and has become an important tool for converting AW into added value. In this context, studies conducted in Türkiye, as well as the current position, capacity development, and scalability potential of domestic companies and academic institutions in this field, should also be examined.

SFE technology in Türkiye is a developing field at both academic and industrial levels, particularly in the context of obtaining high-value-added bioactive compounds from AW. Three key factors stand out in the widespread adoption of this technology: policy and support mechanisms, academic and industrial R&D activities, and domestic machinery production capacity.

The 2022 report "Target-Oriented R&D and Innovation Issues and Priority Products/Technologies in the Agriculture and Food Sector," published by TÜBİTAK-TAGEM, does not directly mention SFE, but emphasizes the need to support priority areas such as "obtaining high-value-added products from AW" and "developing functional food ingredients and production technologies." These projects promote the extraction of bioactive compounds from plant, animal, and aquatic wastes, aiming to develop innovative extraction technologies for functional foods, natural cosmetics, and pharmaceutical products.

Studies conducted by various universities and research centres in Türkiye, particularly TÜBİTAK-MAM, are experimentally examining the performance of SFE systems on AW. These studies aim to optimize SFE by analyzing the effects of parameters such as temperature, pressure, and solvent flow rate on extraction efficiency. Academic literature contains numerous application examples for extracting extracts from agro-industrial wastes such as propolis, olive pulp, and grape seeds (Keskinkaya et al., 2023; Akgün & Akgün, 2006; Yıkar et al., n.d.; Şahin, 2011; Ergüt, 2015; Yavuz, 2023; Ateş, 2017; Dervişoğlu et al., 1996; Baysal et al., 2000; Şanal et al., 2004).

In addition to academic studies, domestic production of SFE systems is also developing in Türkiye. Companies such as Superex, Polat Makina, and Arşen Process are developing laboratory, pilot, and industrial-scale SFE systems, offering solutions for both the domestic market and exports. These companies contribute to environmentally friendly and sustainable production goals through the use of high-pressure CO_2 systems, solvent-free extraction processes, and energy-efficient designs. Superex Supercritical covers a wide range of applications, from small-scale laboratory systems to high-volume industrial extraction lines. Superex Supercritical's systems are particularly used in natural products, food, pharmaceutical, cosmetic, and environmental applications. The company also contributes significantly to the widespread adoption of SFE technology in Türkiye by developing optimization parameters for applications such as caffeine removal, propolis extraction, and the production of cosmetic ingredients (SUPEREX, 2025). Polat Makina and Arşen Process, on the other hand, specialize in the production of industrial machinery and extraction equipment. Polat Makina has been operating in the field of food processing machinery and process technologies for many years, enabling the integration of SFE technology into various industries with its high-pressure extraction systems (Polat Makina, 2025). Arşen Process stands out with its engineering design strengths, offering customized SFE solutions for both domestic and export markets (Arşen Process, 2025). It can be argued that all three companies play a significant role in the development and commercialization of SFE systems, ensuring their integration into industrial applications. Domestic production of SFE systems in Türkiye reduces dependence on imported equipment and enables the production of high-value-added products through research and development (R&D) activities.

These studies demonstrate that significant scientific progress has been made in Türkiye regarding the extraction of bioactive compounds from AWs using SFE. However, overall, applications in Türkiye remain largely laboratory-scale, with limited pilot and industrial integration. This suggests that the technology's commercialization potential has not yet been fully realized. However, leading companies in this field in Europe and the United States (e.g., Indena S.p.A. from Italy and Flavex Naturextrakte GmbH from Germany) are successfully applying SFE technology on an industrial scale and offering high-value-added bioactive compounds to international markets. Given Türkiye's rich AW profile, strong agricultural production infrastructure, and developing domestic machinery production capacity, there is a suitable basis for the industrial dissemination of SFE technology. In this regard, Türkiye's competitiveness in this field can be significantly enhanced by increasing public support, encouraging pilot plant applications, and strengthening university-industry collaborations.

2.8. Economic Value of Bioactive Compounds: Market Overview and Price Ranges

Assessing the economic value of bioactive compounds requires a holistic assessment of global and national market dynamics, price ranges, and production potential. This section summarizes the current market landscape and the strategic importance of these compounds for Türkiye.

2.8.1. Global Market Outlook

The increasing demand for bioactive ingredients in functional foods, dietary supplements, cosmetics, and pharmaceutical sectors has driven remarkable growth in the bioactive ingredients market in recent years. The global market is projected to reach $50-52 billion by 2025, increasing to approximately $72 billion by 2030 and $91 billion by 2033 (Mordor Intelligence, 2025; IMARC Group, 2024). Some sources report that, due to comprehensive ingredient definitions, this figure is expected to reach $173-216 billion, exceeding $317 billion by 2030 and $451 billion by 2025 (Future Market Insights, 2023; Grand View Research, 2024). While these differences vary depending on the bioactive ingredients involved and the methodological scope, all reports indicate a market growth rate of between 6% and 8% compound annual growth.

The bioactive ingredient market is divided into various subsegments based on ingredient type, including plant-based polyphenols, carotenoids, phytosterols, flavonoids, dietary fibre, prebiotics, omega fatty acids, enzymes, and protein derivatives. Among these segments, polyphenols and flavonoids, in particular, stand out as the fastest-growing groups due to their positive health effects and versatile applications (Mordor Intelligence, 2025).

Polyphenols are in high demand due to their potent antioxidant capacity and effectiveness in anti-ageing applications. The global polyphenol market size is reported to be approximately $2.8 billion by 2025, with an average annual growth rate of 7.5% (Mordor Intelligence, 2025). Similarly, the flavonoid market, which reached $1.2 billion by 2025, is expected to reach $2.5 billion by 2035 and continue to grow at a 7.7% compound annual growth rate (CAGR) during this period (Future Market Insights, 2025).

Meanwhile, carotenoids are widely used in both the functional food and cosmetics sectors, with a market value of approximately $2.1 billion by 2025. This segment has an average annual growth rate of 4.6%, and lycopene, beta-carotene, and astaxanthin are the leading subtypes (Mordor Intelligence, 2025). Furthermore, pigments, distinguished by their colouring properties, are utilised not only in food but also in cosmetic and pharmaceutical products. The global natural pigment market is approximately $6.9 billion as of 2025 and is expected to reach $10.2 billion by 2035, growing at an annual CAGR of 4.3% during this period (Future Market Insights, 2025).

When analysed by area of use, it is noted that bioactive ingredients are most commonly used in functional foods and beverages, followed by food supplements and nutricosmetics (personal care products). Anti-ageing products and immune-supporting supplements, in particular, have been areas of increased consumer interest following the COVID-19 pandemic (Allied Market Research, 2022).

In terms of geographic distribution, Europe maintains the highest market share. EU regulations on food safety and clean labelling have driven producers and consumers in this region to natural-based bioactive ingredients. Meanwhile, the Asia-Pacific region stands out as the fastest-growing region. This growth is fueled by the strong traditions of natural medicine and increasing healthcare spending, particularly in countries such as China, India, and Japan. North America remains a leading market, particularly for nutraceuticals and functional beverages (Allied Market Research, 2022; Mordor Intelligence, 2025).

Key factors supporting growth in the bioactive ingredients market include: The rapid expansion observed in the functional food and beverage market, increasing consumer demand for clean-label and natural-ingredient products, the shift in health-based consumption habits of the aging population, rising health awareness in developing countries, the pursuit of sustainable production to reduce food waste, and the proliferation of recycling technologies (Mordor Intelligence, 2025; Vilas-Boas et al., 2021). In line with these dynamics, bioactive components derived from AW are recognised as having strategic importance, not only as raw materials with economic value, but also in the context of environmental sustainability and circular economy principles (Vilas-Boas et al., 2021).

The market is highly competitive in terms of company distribution. Major global players, including BASF SE, DSM-Firmenich, Archer Daniels Midland Company (ADM), Cargill Inc., and DuPont, stand out (Future Market Insights, 2024). These companies maintain their market leadership by offering integrated solutions using both raw material production and advanced extraction methods. Additionally, more niche but highly specialised companies such as Sabinsa Corporation, Lonza Group, and Kerry Group hold a significant place in the market with plant-based extracts and targeted bioactive formulations (Future Market Insights, 2025).

This market expansion has led not only to an increase in the number of manufacturers but also to a diversity of pricing strategies. Unit prices for bioactive ingredients vary significantly depending on several factors, including the ingredient's chemical class, purity, extraction method (e.g., SC-CO_2 extraction), production scale, supply chain structure, and end-use sector (e.g., food, cosmetics, or pharmaceuticals). Direct and up-to-date data on unit prices are not presented in most market research reports. However, practical studies in the literature and information obtained from various commercial sales channels provide an important perspective on the price ranges of bioactive ingredients. Table 2 below compiles the unit price ranges reported in the literature for extracts obtained from AW using SFE. These prices vary according to different purity levels and usage areas for both bulk extract and specific compound-based products.

Table 2. Literature-Based Unit Price Ranges of Bioactive Extracts

Product	**Residue**	**Extract**	**Price Range* (USD/kg)**	**Source**
Grape	Peel, Pomace, Seed	Resveratrol-rich extract	8-5,000	Tridge (2024); Arias et al. (2023); Carla Da Porto et al. (2022); Fiori (2010)

Table 2. (continued)

Tomato	Peel, Pomace, Seed	Lycopene-rich extract	8-2,183	Yadav et al. (2023); Almeida et al. (2024); Popescu et al. (2022); Scaglia et al. (2020)
Olive	Leaf, Cake	Hydroxytyrosol-rich extract	70-1,800	Fotiadou et al. (2024); Juan Miguel Romero-García et al. (2016)
Olive	Leaf, Cake	Oleuropein-rich extract	70-300	Juan Miguel Romero-García et al. (2016); Romani et al. (2016)
Orange	Peel	Limonene-rich extract	320-350	Victor et al., (2022)
Orange	Peel	Flavanone-rich extract	100-200	Lachoz-Perez et al. (2020)
Avocado	Peel	Quercetin-rich extract	70-130	Daissy Lorena Restrepo-Serna et al. (2022)
Avocado	Seed	Catechin-rich extract	10-300	Daissy Lorena Restrepo-Serna et al. (2022)

** The above values represent the commercial price ranges for bioactive ingredients obtained through dry residue-based SFE. Prices vary depending on the purity of the extract, production scale, use of co-solvents, and type of extract.*

As shown in Table 2, unit prices for bioactive extracts obtained from AW through SFE vary widely depending on the ingredient type, purity level, production scale, and processing conditions. In particular, with increasing purity levels, the unit price of some extracts, such as resveratrol, lycopene, and hydroxytyrosol, can exceed $1,000 per kg, demonstrating the high value-added potential of these ingredients.

2.8.2. Türkiye Market Outlook

In line with global trends, a significant increase in health-based consumption trends, functional food applications, and the use of plant-based products is observed in Türkiye (Gök & Ulu, 2019; Karadağ et al., 2022). The market, which stood at approximately $165 million by 2024, is expected to reach USD 274 million by 2032, growing at a CAGR of 8.8% during this period (Data Bridge Market Research, 2024).

When evaluated by usage area, the functional foods segment holds the largest share, with approximately USD 52 million in 2024. This segment is projected to be the fastest-growing area with a CAGR of 11.3% between 2025 and 2032. This is associated with the increasing popularity of consumer health-oriented products and the rising demand for foods enriched with functional ingredients (Data Bridge Market Research, 2024).

When analysed by ingredient type, peptides emerge as the largest subsegment in the market, with a projected value of approximately \$31 million by 2024. Peptides are also reported to be the fastest-growing ingredient group, with an annual growth rate exceeding 10%. This is particularly related to their growing use in sports nutrition, anti-ageing products, and skin health (Data Bridge Market Research, 2024). When classified by source, plant-based bioactive ingredients lead the market, with a market volume of approximately \$70 million. The rise in this segment is projected to continue, with an annual growth rate of 9.5% (Data Bridge Market Research, 2024).

These data indicate that the bioactive ingredient market in Türkiye is on a growth trajectory and that the domestic market for bioactive ingredients is expanding. This expansion in the domestic market demonstrates that the potential for domestic production presents a strategic opportunity for growth. To effectively utilise this potential, the current foreign trade structure of the relevant ingredients should also be examined. In particular, for specific bioactive compounds where domestic production capacity is limited or uncertain, demand analyses based on import and export data are crucial for revealing the level of external dependence of the domestic market. In this context, a pre-feasibility study prepared for the establishment of a beta-carotene production facility in Konya province detailed the production capacity, foreign trade data, and domestic demand analyses for beta-carotene and vitamin A products (Ministry of Industry and Technology, 2021).

The study stated that carrots would be used directly as the primary input in beta-carotene and vitamin A production, highlighting the inadequacy of production in this area in Türkiye. According to the demand analyses in the study, as of 2020, a total of 1,198 tons of beta-carotene (GTIP 320300109000) were imported into Türkiye at a unit price of approximately \$12/kg, resulting in approximately \$15 million in expenditures. In the same year, 547 tons of beta carotene were exported at a unit price of approximately \$13/kg, generating approximately \$7 million in revenue. Similarly, as of 2020, a total of 925 kg of vitamin A (GTIP 293621000019) was imported at a unit price of approximately $122/kg, resulting in payments of approximately $112,000. In the same year, 20 kg of vitamin A was exported at a unit price of approximately $195/kg, generating $3,000 in revenue (Ministry of Industry and Technology, 2021). These data for beta carotene and vitamin A reveal significant domestic demand in Türkiye. The high import levels and almost nonexistent domestic production indicate significant investment potential in this area. For example, as of 2020, Türkiye's net beta carotene imports were 651 tons. Assuming no stocks or domestic production, this amount can be considered the minimum domestic demand.

Table 3 was prepared using the same methodological framework applied in the Konya pre-feasibility study for beta-carotene, but extended here to cover other bioactive compounds. Within this approach, domestic demand levels for vitamin E, oleic acid, linoleic acid, squalene, and quinone were assessed by assuming negligible domestic production and calculating net demand through foreign trade data. For each compound, the relevant “Gümrük Tarife İstatistik Pozisyonu” (GTIP) codes—corresponding to the international Harmonized System (HS)—were identified, and five-year averages of imports and exports were analyzed to estimate demand volumes.

Table 3. Five-Year Average Trade Balance of Bioactive Compounds (2020–2024)

Compound	GTIP Code	Avg. Import Quantity (kg)	Avg. Export Quantity (kg)	Avg. Import Price (USD /kg)	Avg. Export Price (USD /kg)	Avg. Import Value (1,000 USD)	Avg. Export Value (1,000 USD)	Avg. Domestic Demand (kg)
Vitamin E	293628000011	148,797	15,725	20.20	24.80	2,780.12	318.65	133,072
Oleic Acid	291615001000	365,875	376,102	1.97	1.16	670.31	487.24	–10,227
Linoleic Acid	291615009011	25,325	33	4.12	18.00	105.84	2.99	25,292
Squalene	290129001000	39,922	81,175	19.44	20.20	409.62	1320.96	–41,253
Quinone	291469800011	1,832	13.5	29.60	146.50	53.73	0.99	1,818

Source: Author’s Calculations based on ITC Trade Map Data

The five-year average foreign trade data in Table 3 reveal high domestic demand and external dependence for some bioactive compounds in Türkiye. Vitamin E stands out with an average import volume of around 149,000 kg, while exports total only 15,700 kg, resulting in a net domestic demand of approximately 133,000 kg. This demonstrates that the Vitamin E market in Türkiye is highly dependent on external sources and that domestic production remains extremely limited. This compound, which offers significant investment opportunities, is also notable for its import prices, which average $20.2/kg. On the other hand, for oleic acid, exports exceed imports, with an average annual export of 376,000 kg and an import of 366,000 kg, resulting in a net demand of 10,000 kg. This table demonstrates that oleic acid is produced in Türkiye, and that production for the foreign market exceeds domestic demand. For linoleic acid, imports are approximately 25,000 kg, while exports are virtually nonexistent. This suggests that the market is small in size but entirely dependent on foreign sources.

For the compound squalene, annual exports totalled approximately 81,000 kilograms, compared to imports of approximately 40,000 kilograms. This net export status indicates that squalene production in Türkiye is robust, and domestic demand is primarily met by domestic production, resulting in an export surplus. For the compound quinone, imports averaged 1,832 kg/year, while exports totalled only 13.5 kg. This indicates a domestic market that is almost entirely dependent on imports, with a net demand of around 1,818 kg/year. In this context, it is assessed that investment opportunities exist for bioactive compounds with limited or no domestic production, and that strategies can be developed to reduce Türkiye's external dependence in this area.

2.9. Economic Impact Assessments: Micro-Level and Macro-Level Approaches

The production of bioactive compounds from AW is expected to be not only technically feasible but also economically sustainable, creating a meaningful value chain. Micro- and macro-level economic evaluation approaches are available to analyze the cost-effectiveness of production processes and examine the impact of production on the national economy. This section summarizes microeconomic analysis methods commonly used in the literature, followed by a discussion of the scope, application areas, and contributions of I-O-based macroeconomic analyses.

2.9.1. Micro-Level Economic Estimation Approaches

Micro-level approaches to assessing the economic feasibility of bioactive compound production from AWs allow for analysis based on parameters such as cost, efficiency, and return on investment on a process-by-process basis. In this context, the cost of production (COM) is a critical evaluation parameter for investment and process decisions.

Cost of manufacture (COM) represents the monetary equivalent of the inputs required to produce a specific product in the desired quantity, in compliance with quality and safety standards. This cost includes not only the raw materials used but also labour, energy, equipment depreciation, maintenance, waste management, auxiliary chemicals, losses incurred during the process, and other production-specific expenses (Rosa & Meireles, 2005).

COM is used as a key parameter in pre-feasibility studies, particularly those conducted to assess the economic viability of new technologies. This calculation is crucial for process-based decision support systems, as it directly impacts the product's market competitiveness, return on investment (ROI), and profit margin (Fiori, 2010; Restrepo-Serna & Cardona Alzate, 2022). In other words, COM represents the total economic burden of the production process and serves as the actual cost baseline for a product before it is released to the market (Nguyen & Khong, 2017).

According to the classification established by the International Association of Cost Engineering (AACEI), cost estimates in industrial projects are generally divided into five classes (Class 1–5). This classification is based on the level of project definition, the intended use of the estimate, the methods used, the accuracy range, and the effort required for preparation. As the project matures, the cost estimation process progresses from uncertain and guesswork-based (stochastic) methods to more realistic (deterministic) models (Meireles, 2008; Prado et al., 2017). In line with this classification, the cost estimation process is not considered a static calculation, but rather a dynamic evaluation process that evolves in parallel with project progress.

Class 5 estimates are typically made in the early concept development stages, when only minimal information about the project, such as capacity, facility type, and location, is available. Estimates at this level have the broadest range of accuracy and are often based on stochastic methods. Capacity/cost curves, parametric models, and various factor coefficients are commonly used in such analyses. Class 4 estimates are developed for feasibility analyses and preliminary budgeting. Although the level of information is still limited, the availability of specific technical documentation and the clarification of process flows enable more systematic estimation. This class also primarily employs stochastic methods (Meireles, 2008; Prado et al., 2017).

Class 3 estimates are prepared to obtain budget approval for the project and facilitate cost control in later stages. At this level, engineering documentation, including process diagrams, preliminary layout plans, and equipment lists, is now available. Estimates are primarily based on deterministic methods, although stochastic techniques are also employed for specific uncertain subcomponents. Class 2 estimates are most commonly used in tender preparation and contract-based bidding processes. The project's detailed engineering is 30–60% complete. The methods used in this class provide high accuracy, with estimates based on engineering calculations, technical drawings, and supplier proposals. Class 1 estimates, on the other hand, involve the highest level of accuracy, with nearly all technical information for the project being complete and accurate. Estimates at this level are generally performed only for critical project components and are primarily based on actual design measurements (Meireles, 2008; Prado et al., 2017).

Cost analyses in the literature on SFE are primarily based on laboratory or pilot-scale data. For this reason, these studies, which have a low level of definition and are not based on engineering documentation, are generally evaluated within the scope of Class 5–4 (Fiori, 2010; Rosa & Meireles, 2005; Restrepo-Serna & Cardona Alzate, 2022). These analyses are based on process data, including extract yield, S/F ratio, and extraction time. In contrast, cost items such as fixed capital investment (FCI), labour (COL), auxiliary services (CUT), and raw material preparation (CRM) are estimated using coefficients derived from similar systems (Rosa & Meireles, 2005; Turton et al., 1998). While FCI generally covers equipment, installation, and engineering infrastructure, COL covers the costs of personnel working in the production process and varies depending on the level of automation of the system (Fiori, 2010; Nguyen & Khong, 2017; Prado et al., 2017). The CRM item, on the other hand, includes the cost of pretreatment processes such as drying and milling, although the purchase price is generally assumed to be zero in AW-based systems (Rosa & Meireles, 2005; Shariaty-Niassar et al., 2009). The cost of waste treatment (CWT) should be considered a significant environmental cost element in SFE systems. However, because SFE processes do not produce toxic or hazardous waste, this element is either neglected or reported at very low levels in many studies (Rosa & Meireles, 2005; Brunner, 2005). CUT, on the other hand, depends on variables such as energy, solvent, and cosolvent consumption, as well as recovery efficiency, and typically accounts for the smallest share of the total cost, approximately 1% (Fiori, 2010; Restrepo-Serna & Cardona Alzate, 2022).

Fiori (2010) presented a preliminary feasibility analysis for the production of grape seed oil from grape pomace using SFE, based on laboratory and pilot-scale data. The study designed an industrial-scale SFE capable of processing 3,000 tons of grape pomace per year. The findings showed that while grape seed oil sold in the market is priced between €10 and € 30/kg, SFE-produced grape seed oil can be produced for € 5.90/kg. This demonstrates that grape pomace processing with SFE can produce grape seed oil cost-effectively.

Scaglia et al. (2020) designed a biorefinery-based SFE process for the production of lycopene from tomato peel and seed pulp based on laboratory and pilot-scale data. The study reported that a canning factory processing 60,000 tons of tomatoes annually produces 1,800 tons of tomato pulp per hour, and that SFE extract could be produced from this pulp for €21.28/kg. While the market price of lycopene is reported to be €50/kg, the cost of crystalline lycopene is reported to be €3,000/kg, and the cost of tomato oleoresin-based extract containing 1% lycopene can reach €5,000/kg. These differences in market prices vary depending on the production method, purity level, and physical form of the extract.

Restrepo-Serna & Cardona Alzate (2022) developed an economic analysis model for wastes such as mango peel, passion fruit, raspberry, and mandarin peel, based on experimental SFE data from the literature, and clearly defined the estimation process as an early-stage feasibility analysis. In the study, an SFE process with a 100 kg/h feedstock flow was designed, and economic analyses were conducted using the Aspen Process Economic Analyzer. The findings showed that while market prices for mango peel, passion fruit, raspberry, and mandarin peel extracts were $12.55, $16, $9, and $8/kg, respectively, the SFE-derived extracts could be produced for $11.69, $2.09, $4.8, and $4.92/kg, respectively.

Daissy Lorena Restrepo-Serna et al. (2022) developed an economic analysis model for the production of quercetin and catechin from avocado seeds and peels based on experimental SFE data in the literature. The study designed a biorefinery-based SFE process with a feedstock flow of 1000 kg/h and conducted economic analyses using the Aspen Process Economic Analyser. The economic analyses indicated that market prices for quercetin and catechin ranged from $70 to $ 130/kg and $10 to $ 300/kg, respectively, with unpurified extracts typically costing between 10% and 50% of the purified main ingredient. The findings indicated that extracts from avocado waste could be produced for prices ranging from $3.99 to $8.27/kg.

Rosa María Fonseca-Pérez et al. (2024) compared three different grape seed oil production methods: hexane extraction, SFE, and SFE + ethanol combined, from an economic and environmental perspective. The economic analysis in the study reported that the market price of grape seed oil ranged from $14 to $40/kg. The findings indicated that SFE + ethanol and hexane extractions yielded similar yields; however, the production cost for SFE + ethanol extraction was $8.61/kg, whereas the cost of hexane extraction was $6.31/kg. The primary reason for this difference in production costs is the higher setup cost for the SFE + ethanol method compared to the hexane method. However, when using only SFE, the production cost ($6.29/kg) was reported to be similar to the SFE + ethanol method.

These examples demonstrate the effectiveness of Class 5–4 pre-feasibility analyses, particularly those based on laboratory or pilot-scale data, in shaping initial investment decisions. The COM models developed in this context provide valuable tools for mitigating pre-investment uncertainties, evaluating the potential for process optimization, and enhancing resource efficiency. However, these approaches focus on the production process and are insufficient to assess broader socioeconomic impacts. Therefore, macro-level analysis methods are employed to assess the impact of these production scenarios on the national economy.

2.9.2. Macro-Level Impact: Input–Output and Bioeconomy Models

While micro-level analyses offer process-level economic feasibility by focusing on the production process, they fall short in assessing socioeconomic impacts such as intersectoral interactions, employment, and value added. However, recycling AW into the economy can create multidimensional impacts such as increased sector diversity and employment, import substitution, and increased export potential. Therefore, macro-level analyses are needed to assess the total impact of production processes on the national economy. For this purpose, I-O analysis is used.

I-O analysis, first developed by Leontief, is a systematic approach that quantitatively models the I-O relationships between sectors in an economy (Pehlivanoğlu & İnce, 2020). In other words, it is used to determine the equilibrium conditions under which industries within an economy produce enough to meet both their internal demands and external demands (Özdemir & Mercan, 2012). This model, based on the assumption that each sector provides both intermediate goods input and final product output during the production process, treats the economy as an internal interaction matrix (Uğurlu & Tuncer, 2017). This matrix is known as the I-O table.

I-O tables are prepared within the framework of the definitions, concepts, and methods found in the United Nations System of National Accounts. Due to the complexity of data preparation processes, these tables, which are generally updated every five years, were first used in Türkiye during the First Five-Year Development Period (Boysal, 1980; Özdemir & Mercan, 2012). The most current table is the 64-sector symmetric I-O table published by TUIK based on 2012 (TUIK, 2012). This matrix shows, in monetary terms, how much goods and services each sector receives from other sectors and to which sectors it provides output. Symmetric I-O tables have a square matrix structure in which sectors participate in the system as both buyers and sellers. The rows in the matrix represent sector outputs, while the columns represent the monetary equivalents of the inputs a sector receives from other sectors during production (Ramirez et al., 2025). In summary, the off-diagonal cells of the matrix represent inter-sectoral interactions, while the diagonal elements represent the inputs used by the sector itself.

I-O tables include inter-sectoral interactions, as well as end-use and value-added components. End-use refers to the extent to which a sector's production is directed toward items such as consumer spending, private sector investments, public procurement, and exports (Pehlivanoğlu & İnce, 2020). Value-added components, broken down into sub-items such as wage payments, taxes, depreciation, and imports, allow us to measure the economic contribution sectors derive from internal resources during their production activities and their dependence on external resources (Uğurlu & Tuncer, 2017).

Multiplier coefficients are generated from the symmetric I-O table using the technical coefficients matrix and the Leontief inverse matrix approaches (Uğurlu & Tuncer, 2017; Pehlivanoğlu & İnce, 2020). These coefficients are used to assess the diffusion power of intersectoral economic linkages (Pehlivanoğlu & İnce, 2020). Intersectoral linkages are categorized into two types: forward and backwards linkage coefficients. Forward linkage coefficients indicate the extent to which other sectors use a sector's output and are calculated by summing the columns of the Leontief inverse matrix in the relevant sector. The backwards linkage coefficient indicates the extent to which a sector receives inputs from other sectors for its output and is calculated by summing the rows of the Leontief inverse matrix in the relevant sector (Uğurlu & Tuncer, 2017). These coefficients, calculated using the Leontief inverse matrices, represent indirect effects. Indirect effects measure the impact of a sector's output on the demand for intermediate goods and the production of other sectors. Direct effects, on the other hand, represent the initial increase in output production in the relevant sector and are calculated using a technical coefficient matrix (Pehlivanoğlu & İnce, 2020).

These coefficients, used in the analysis of inter-sectoral linkages, are also used to determine sectoral importance levels. Sectoral importance levels are examined in four different categories, as suggested by Hirschman (Pehlivanoğlu & İnce, 2020). The first category includes sectors with high forward and backwards linkages. The second category includes sectors with low forward linkage effects but high backwards linkages. The third category includes sectors with high forward linkage effects but low backwards linkage effects. The fourth category includes sectors with low forward and backwards linkage effects. For example, sectors responsible for the production of intermediate goods fall into the third category, while sectors utilizing natural resources are categorized in the second category (Pehlivanoğlu & İnce, 2020; Özdemir & Mercan, 2012).

In recent years, the number of I-O-based studies examining the impact of the bioeconomy on the economy has increased, and examples from various countries have been presented in the context of sectoral impacts. In these examples in the literature, alternative methods such as the extended approach (adding a new sector) and the synthetic sector approach (demand shock identification) are preferred because bioeconomy-based sectors are not included as separate sectors in I-O tables (Gözkün & Orhangazi, 2025; Garrett-Peltier et al., 2017; Miller & Blair, 2009). However, the demand shock approach is generally preferred because adding a new sector to an existing I-O table in the extended approach requires complex and time-consuming techniques. The demand shock approach assumes that a new sector utilizes output from existing industries in its production process but does not sell its products to existing sectors, thereby treating the system as a system of final consumption goods only (Gözkün & Orhangazi, 2025; Miller & Blair, 2009).

Song et al. (2015) examined the energy, economic, and environmental performance of five different bioenergy technologies used for energy production from AW in China over 15 years, employing I-O analysis. The study simulated electricity generated from bioenergy technologies and solid, liquid, and gaseous biofuels integrated with the regional economic structure. The results indicated that it is possible to produce approximately 8 million tons of coal equivalent bioenergy from 55 million tons of AW by 2025. This result reduces greenhouse gas emissions by 3.1% compared to the baseline scenario. The findings aim to provide policy recommendations for the industrialization of bioenergy technologies.

Malik et al. (2015) conducted a multi-regional I-O model and hybrid life cycle analysis to assess the environmental, economic, and social sustainability of algae-based biocrude production in Australia. The results showed that annual biocrude production of 1 million tons could generate approximately 13,000 new jobs and contribute $4 billion to the economy.

Wang et al. (2020) integrated the bioethanol sector as a new industry into China's multi-regional I-O table and applied a final demand shock to the model. By applying a specific monetary demand level (e.g., 100 million yuan) to the bioethanol sector, the researchers analyzed the social (employment), economic (income and production impact), and environmental (energy consumption) consequences of this shock across the economy. This approach, using the Leontief inverse matrix, enabled direct and indirect impacts to be tracked throughout the entire supply chain. This comprehensive assessment of the bioethanol sector's production impacts and its interactions with other sectors has been achieved. This method is a classic application of final demand shocks, frequently used in I-O models and helpful in analyzing the pervasive effects of sectors within the system.

Lazorcakova et al. (2022) evaluated the economic and environmental contributions of the bioeconomy in the Visegard countries (Slovakia, the Czech Republic, Poland, and Hungary) using an I-O analysis. The study calculated the current and potential bioeconomy size based on scenarios based on biobased product associations. The results showed that bioeconomy-based production contributes 13% of output, 10% of value added, 15% of employment, and 20% of greenhouse gas emissions. This enables the bioeconomy to be viewed as a development tool that is compatible with both economic growth and environmental sustainability goals, and also provides policymakers with concrete indicators for sectoral prioritization and resource allocation.

Arnic et al. (2024) analyzed the potential impacts of the wood-based bioeconomy in Slovenia on sustainable transformation and carbon reduction using an I-O model. Using Slovenia's 2015 I-O table, conventional and biobased production in wood-based sectors were separated, and multiplier coefficients for sub-sectors were calculated. In the most optimistic scenario, a 17% increase in total output was observed in the wood-based bioeconomy sector, accompanied by a 20% increase in employment and a 16% increase in income. The study provides a quantitative basis for strategic planning in the wood-based bioeconomy from both industrial and public policy perspectives.

Ramirez et al. (2025) examined the impacts of biobased industrial activities in Colombia on the country's production structure and intermediate consumption patterns through I-O analysis. The study applied a 10% demand increase scenario to bioeconomy-based sectors, reporting a production increase of approximately 9%. The study highlights the strategic importance of biobased sectors in natural resource-based economies and provides guidance for policy design to promote sustainable development.

Gözkün and Orhangazi (2025) analyzed the economic and environmental impacts of investments in solar and wind energy in Türkiye in line with the 2053 net-zero target. The study evaluated the impacts on emissions, employment, economic growth, and the foreign trade balance within the scope of 10-year investment scenarios using I-O analysis and the employment coefficient approach. The study updated the official I-O table from 2012 to 2020 using the RAS method, incorporating updated data on sectoral production, value added, and intermediate input relationships. The RAS method is a rescaling technique that allows the matrix to be updated while maintaining the row and column totals in the I-O table. The results showed that these investments could reduce emissions by 28–77%, contribute 0.6–1.8% to Gross Domestic Product (GDP) annually, and create nearly 1 million new jobs. Furthermore, the foreign trade balance was improved thanks to the reduction of import-dependent energy sources.

These studies demonstrate that I-O-based analyses are an important tool in revealing the economic, environmental, and social impacts of bioeconomy-focused production activities. According to Hirschman's sectoral classification, production activities based on the recycling of AW can be classified as the second category. These sectors provide intermediate inputs to numerous sectors during the production process, while their outputs are utilized in a limited number of sectors, thereby generating high diffusion potential through indirect impact channels (Pehlivanoğlu & İnce, 2020; Özdemir & Mercan, 2012). The fact that bioactive compounds obtained from AW through SFE are directed to specialized uses, such as the food, cosmetics, and pharmaceutical industries, indicates a narrow forward linkage. In contrast, the need for inputs from numerous sectors, such as agriculture, energy, transportation, chemicals, and labour, indicates a strong backwards linkage. In this context, the sectoral impacts of these activities should be assessed not only through the final uses of the output but also through diffusion channels such as intermediate input demand and employment creation. This study analyzes the output, value-added, and employment impacts of AW-based production scenarios in Türkiye. Thus, not only is the economic contribution of these activities demonstrated, but also their compatibility with sectoral transformation and sustainable development goals.

CHAPTER 3

METHODOLOGY

3.1. Overall Research Method and Progression

This study aims to reveal the quantity and economic value of components that can be produced from agricultural reisdue in Türkiye through SFE and to analyze the macroeconomic impacts of this production, providing a data-based overview for the literature and policymakers. In this context, a multi-stage, data-driven, and comparative methodology was adopted, integrating agricultural production data with literature findings to create an analytical framework. The study's methodological structure consists of five main stages, which are illustrated in Figure 2.

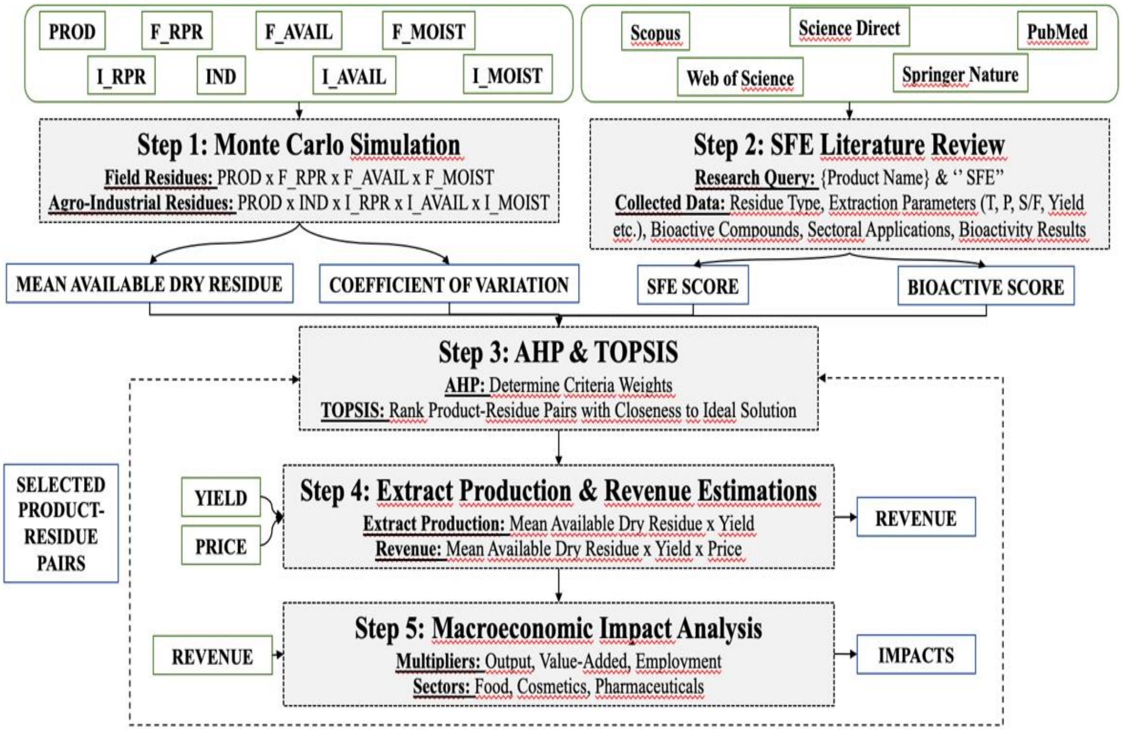

Figure 2. Methodology Overview

The first stage involves calculating the amount of field and agro-industrial residue from agricultural products produced in Türkiye. These calculations are made using parameters such as product-based production data, RPR, industrial processing rate, industrial residue rate, moisture content, and collectability coefficient. A Monte Carlo simulation was employed to incorporate uncertainties in the study's parameters. To perform a Monte Carlo simulation on the agricultural product profile included in the study, the optimum number of iterations was determined through sensitivity analyses. For the AR profile simulated with the optimum number of iterations, the theoretical residue amount, available residue amount, theoretical dry residue amount, and available dry residue amounts were calculated for each product, with 5% and 95% confidence intervals corresponding to the minimum, average, and maximum scenarios. The coefficient of variation (CV) was calculated for each product to assess the uncertainty level of the simulation results.

The second stage involves a systematic literature review based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. At this stage, only agricultural products for which AR amounts could be calculated in the first stage were considered. In other words, products for which the necessary parameters for residue calculation (RPR, processing rate, moisture, collectability, etc.) were not available in the literature were excluded. For products with AW profiles, a systematic search was conducted in Scopus, Web of Science, Science Direct, PubMed, and Springer Nature databases using the keyword combination "product name + SFE" and its derivatives. A systematic literature review was conducted only for products for which residue amounts could be calculated as a result of the database searches. A two-stage filtering process was applied in the searches conducted with the keyword "product name + SFE." In the first stage, duplicate records were eliminated, and product–residue pairs were identified through text mining, such as tomato–peel, grape–pomace, and olive–cake. In the second stage, the SFE Score was generated based on criteria such as extraction method, parameter information, yield rate, and methodological integrity. This score reflects the robustness and depth of existing SFE studies for each product–residue pair. The Bioactive Score was also calculated, taking into account the functionality and sectoral applicability of the components. This score indicates the potential of each residue to yield bioactive compounds with commercial and functional value in sectors such as food, cosmetics, and pharmaceuticals. Together, these two scores served as the decision criteria in the AHP and TOPSIS analysis, ensuring that both the strength of the scientific evidence and the practical relevance of the compounds were incorporated into the evaluation framework.

The third stage aimed to identify the most suitable types of AR for producing bioactive compounds through SFE. In this context, a multi-criteria decision-making approach was adopted, using both the AHP -TOPSIS methods. The evaluation criteria were (1) the average amount of available dry residue (indicator of supply), (2) the CV ratio (indicator of supply instability), (3) the SFE Score (indicator of technical adequacy), and (4) the Bioactive Score (indicator of value-added potential).

This approach is widely used in the literature to prioritize agricultural and biomass-based resources. For example, a study conducted by Osei et al. (2023) used the AHP method to determine the most suitable AR types for use in biomass gasification systems in Ghana, employing criteria weights. Then, alternatives were ranked using methods such as TOPSIS, VIKOR, and COPRAS. Similarly, in a study conducted by Zoma and Sawadogo (2023) in Burkina Faso, a multi-criteria analysis based on AHP–TOPSIS was used to determine suitable agricultural and agro-industrial residue types for energy production from biomass. The criteria used in this study included dimensions such as biomass accessibility and availability, competitive use level, environmental pollution potential, economic impact, energy content, and the existence of appropriate conversion technologies. These examples demonstrate that multi-criteria decision-making approaches, such as AHP–TOPSIS, can be effectively used as a flexible and holistic decision support tool in biomass selection and prioritization analyses.

The fourth stage involves calculating the quantities of extracts and specific bioactive compounds that can be produced using SFE from AR prioritized by the AHP–TOPSIS analysis, as well as their potential market volume. These quantities were calculated based on the amount of available dry residue obtained in the first stage and the yield values obtained in the second stage. Calculations were conducted under minimum, average, and maximum scenarios, taking into account the uncertainty of the yield values. Production quantities were then multiplied by market prices to calculate the potential economic output of the relevant extracts under the minimum, average, and maximum scenarios.

In the final stage, unlike the theoretical scenarios in the fourth stage, practical, realistic scale scenarios were developed, and macroeconomic analysis was conducted based on these scenarios. In this context, to analyze the potential contribution of bioactive compound production to the Turkish economy, supercritical extract production scenarios were defined at 1,000 tons/year (pilot scale), 10,000 tons/year (regional scale), and 30,000 tons/year (national scale), respectively. The potential income corresponding to the production volumes in question was incorporated into the system as a final demand shock in the I-O analysis, and the effects on production, value added, and employment were evaluated within this framework.

3.2. Estimation of Agricultural Residue Profile

Residue quantities were calculated using deterministic formulas based on production data for the relevant products and parameters such as RPR, moisture content, industrial processing rate, and availability coefficient (see 2.3.1). However, the fact that these parameters are reported at different intervals in the literature necessitated consideration of uncertainties. Therefore, a Monte Carlo simulation was implemented, moving beyond deterministic calculations; waste quantities were obtained by random sampling from the distributions defined for each parameter.

For production data, mean and standard deviation values were calculated using a 21-year time series from 2004 to 2024. The distribution structure was assessed using normality tests, such as the Shapiro-Wilk (S-W), Kolmogorov–Smirnov (K-S), and Anderson–Darling (A-D) tests. Within the scope of the analysis, normality tests were first applied to each product with at least five years of data. The Shapiro–Wilk test (using the p-value) and the Anderson–Darling test (using the critical value threshold comparison) were employed. Additionally, to further evaluate the suitability of parametric distributions, the K-S test was applied separately for four different distribution types (gamma, Weibull_min, logistic, and normal). To assess log-normal suitability, the S-W and A-D tests were rerun on the logarithmized production values. When selecting the appropriate distribution, the test results for the log-normal or normal distributions were considered. If these distributions were not found, the distribution with the highest p-value from the K–S test was chosen. For products with production data of less than 5 years, an empirical distribution was preferred over a parametric distribution. Furthermore, because parameters such as RPR, industrial processing rate, industrial residue rate, and moisture content are often reported in the literature as minimum–maximum intervals, and measures of central tendency (e.g., mean, median, or mode) are not provided for these distributions, a uniform or beta distribution was assumed for these uncertain parameters. However, these distribution types were not directly assumed, and fit tests were performed on different distributions for each product and parameter. The availability ratio, which is generally reported as a constant coefficient in the literature, was considered a constant value in the simulations. By modelling all parameters used in the calculations of field and agro-industrial residue in this manner, the estimated waste amounts per product reflect the inherent uncertainties in the distribution.

The number of iterations to be used in the Monte Carlo simulation was determined based on preliminary tests and sensitivity analyses to assess the model's sensitivity to output stability. Variation was controlled at different iteration numbers, and considering the stability of the results' distribution, it was decided to run the simulations using the optimal number of iterations. This achieved an optimal balance between computational cost and statistical reliability. Simulation outputs included the theoretical residue amount, the available residue amount, the theoretical dry residue amount, and the available dry residue amount; minimum, median, and maximum estimated values were obtained for each. Furthermore, the CV was calculated to quantify the uncertainty level of each product-residue pair.

3.3. Literature Database and Text Mining Process

A comprehensive literature review was conducted to assess the current knowledge on the production of bioactive compounds from AR through SFE. Products for which residue quantities could be calculated in the previous step were included in the literature review, and products for which reliable data could not be generated due to a lack of parameters were excluded. The screening process was conducted using the PRISMA approach.

First, systematic searches were conducted for each product using the Scopus, Web of Science, ScienceDirect, PubMed, and Springer Nature databases, with the keyword combination "product name" + "SFE" and its derivatives. During the literature search, a product-based search strategy was adopted rather than a direct keyword search based on "AR." This choice was made because the term "AR" is quite broad in the literature, varies depending on the context, and is referred to by numerous synonyms or overlapping terms. Terms such as "waste," "residue," "by-product," "pomace," "pulp," "husk," and "shell" are often used interchangeably or with different meanings depending on the context, which can lead to data loss in searches directly using "AR + SFE." Therefore, the search strategy was based on product names and a search for publications using the SFE method for each product.

Specific filtering criteria were applied to select the literature: only studies published in 2010 or later, in English, in peer-reviewed journals, and in article format were considered. These filters were determined to ensure the timeliness, academic validity, and linguistic consistency of the retrieved publications. The search results were organized into separate folders for each product and exported in the "ris" format. The collected dataset was then processed using a Python-based workflow, with duplicate records deduplicated where the same study appeared multiple times.

Text mining techniques were then applied to this deduplicated dataset. The title (TI), abstract (AB), and keywords (KW) fields of each record were scanned using a specially developed "residue dictionary" to identify residue types associated with the product. This dictionary was structured to include a wide range of terms commonly used in the literature, such as "pomace," "peel," "pulp," "husk," "shell," "seed," "cake," "fiber," "bagasse," "waste," "residue," and "by-product." Details of the AR dictionary used in the study are provided in Table 4.

Table 4. Agricultural Residue Dictionary

Agricultural Residue Type	Synonyms
Husk	Husk, hull, grain cover
Cob	Cob, maize cob, corn cob
Stalk	Stalk, stalks
Shell	Shell, outer Shell
Straw	Straw, trash, vine, haulm, stubble
Stem	Stem, curd, tops, top, sprout
Leaf	Leaf, leave, foliage, leafy residue
Bran	Bran, aleurone layer
Peel	Peel, skin, exocarp, pericarp, rind, pericarpium
Seed	Seed, pit, pits, kernel, stone, seed pod
Root	Root, rhizome, tuber
Pulp	Pulp, flesh, mesocarp, rag
Pomace	Pomace, marc, fruit marc
Cake	Press cake, oil cake, cake, expeller cake
Bagasse	Bagasse, spent grain
Pruning	Prunings, clipping, branch, cane, shoot, orchard
Discarded	Discarded, low grade, spoiled, spotted, damaged
Placenta	Placenta, peduncle, core, head, spear
Fiber	Fiber, fibrous residue, cellulosic residue
Flower	Flower, inflorescence, floral waste
Bark	Bark, tree bark
Cluster	Cluster, bunch, fruit cluster
Solidwaste	Solid waste, organic waste
Residue	Residue, residues, waste, wastes, by-product, byproduct, processing waste

During the text mining phase, records matching this dictionary were matched at the ‘product + residue’ level, such as tomato–peel, grape–pomace, olive–cake, and orange–peel. Studies containing only extracts or pure components (e.g., seed oil, herbal extract) were eliminated, as were those whose residue type could not be determined. Thus, publications that were out of scope—that is, publications not based on AW or not explicitly stating the product residue—were automatically excluded. However, since information on whether these records included SFE and whether the studies included bioactive compounds was often insufficiently presented in the limited text fields such as title, abstract, and keywords, automatic extraction of these details was not included in the text mining process.

3.4. Development of SFE and Bioactive Compound Indicators

During the text mining phase, records matching this dictionary were matched at the "product + residue" level. Studies containing only extracts of pure components (e.g., seed oil, herbal extract) were eliminated, as were those whose residue type could not be determined. Thus, publications that were out of scope—that is, publications not based on AR or not explicitly stating the product residue —were automatically excluded. However, since information on whether these records included SFE and whether the studies included bioactive compounds was often insufficiently presented in the limited text fields such as title, abstract, and keywords, automatic extraction of these details was not included in the text mining process.

In studies included in the scope as a result of the literature review and text mining process, the automatically matched AR types were verified for accuracy using the title, abstract, and keyword fields. Records where the term " residue " was found to be out of context, incorrect, or inconsistent with the definition of AR were excluded from inclusion.

In studies continuing to be included in the scope, two key indicators were defined for each product-waste pair through an evaluation of the full-text content: the SFE Score and the Bioactive Score. These indicators represent both the technical feasibility (process information, yield, method details, etc.) and the bioeconomic potential (component types, functionality, sectoral equivalent) of product- residue pairs with a holistic approach. The scores were used as the primary inputs to quantify the decision criteria in the multi-criteria decision analysis process that will be conducted in the next stage.

The SFE Score was calculated for each product- residue pair in the context of SFE studies based on the following criteria: (1) the presence of SFE, (2) the level of disclosure of extraction parameters (temperature, pressure, solvent, time, flow rate, etc.), and (3) whether the yield value was presented. In the process of creating the SFE Score, the key content elements of the SFE method were evaluated for each article, and these elements were scored to calculate a score for each product-residue pair. The criteria used to create the SFE score were combined to calculate the total SFE Score for each publication, ranging from 0 to 4. The score structure and scoring system are summarized in Table 5.

Table 5. Structure of the SFE Score and Scoring Criteria

Component	Indicator	Scoring Rule	Score Range
Presence of SFE	SFE_Flag	1 point if SFE method is explicitly mentioned in the study	0 / 1
Extraction Parameters	Parameter_Flag	0: Less than 2 key parameters 1: At least 2 key parameters 2: ≥4 total parameters	0 / 1 / 2
Yield Reporting	Yield_Flag	1 point if yield information is provided	0 / 1
SFE Score		**Sum of individual components**	**0–4**

First, the SFE_Flag variable was defined to determine whether a study included SFE. If the study explicitly included "SFE" in the extraction method field ("Extraction_Type_Info"), the relevant publication was assigned a score of 1.

Next, the number and quality of extraction parameters reported in the studies were evaluated. For this purpose, the number of valid parameters for each publication was calculated from a total of seven parameters (temperature, pressure, time, solvent, cosolvent, S/F ratio, and flow rate). Three of these parameters, specifically temperature, pressure, and time, were defined as "critical parameters"; studies reporting at least two were scored higher. The Parameter_Flag, determined according to these criteria, was structured to take values between 0 and 2: 0 points were assigned if at least two of the critical parameters were missing, 2 points if more than three parameters were reported, and 1 point otherwise.

Finally, yield information ("Yield_Info") was also included in the score. If SFE was used in the study and yield information (e.g., % extract amount or amount of bioactive component such as g/kg) was provided, the relevant publication was assigned a score of 1 from the Yield_Flag. This component indicates that the method's applicability was evaluated, and the results are reported.

Importantly, publications with SFE_Flag = 0, i.e., widespread SFE distributions, were also included in the pool of evaluations. This approach aims to demonstrate that while some individual bioactive systems have been studied, SFE is not methodologically used, and the scoring system can reflect this difference. Thus, uncommon SFE outbreaks have also been reported in the literature, but they have yielded low-scoring results. Furthermore, the parameters used in this scoring were not limited to abstracts, titles, and keywords; the full texts of the articles were scanned in detail. This ensured that critical elements such as extraction parameters and yield information were fully captured.

The Bioactive Score was structured to reflect the potential economic and functional value of the components obtained from each residue. To calculate this score, the types of bioactive components, functional properties, and sectoral application information reported in each publication in the literature were analyzed in detail. Because this information, which is often limited to the title, abstract, and keyword fields, does not fully reflect the content of the study, a systematic review was required, taking into account the full text of the relevant publications. In systematic reviews, the components and sectoral application terms found in the publications were reduced to specific terminology. For example, terms such as "phenolics," "polyphenols," and "flavonoids" were grouped under the same class as "phenolic compounds." Similarly, industry information was categorized homogeneously, and terms such as "nutraceutical application" and "pharmaceutical interest" in the literature were mapped to industry application categories, including "nutraceutical" and "pharmaceutical." This data was used to create the Bioactive Score, which employed a four-stage calculation process.

In the first step of creating the Bioactive Score, the bioactive compound classes reported in each publication were scored according to a predefined value table. In this table, each class was assigned a weighted score between 1 and 5 based on its scientific and commercial significance in the literature. For example, functional and commercially significant compound groups, such as "Phenolic Compounds," "Flavonoids," and "Carotenoids," were assigned a score of 5. In contrast, groups like "Dietary Fibre," "Fatty Alcohols," or "Organic Acids" were assigned lower scores.

Because the "phenolic compounds" and "carotenoids" groups are frequently reported together in the literature and both have similar antioxidant effects, a 10% correction factor (0.9 factor) was applied to the base score to avoid artificially exaggerating the compound diversity when these two classes were included in the same publication. These factors and the evaluation structure are detailed in Table 6.

Table 6. Structure of the Bioactive Score and Scoring Criteria

Component	**Indicator**	**Scoring Rule**	**Weight / Coefficient**
Compound Class Weighting	Base_Score	1 to 5 points based on scientific and commercial value of compound class	1–5
Co-occurrence Penalty for Similar Classes	Adjustment_Factor1	0.9 if both "phenolic" and "carotenoid" classes co-occur to avoid artificial diversity inflation	0.9 / 1.0
Functional Property Reporting	Adjustment_Factor2	1.1 if antioxidant, antimicrobial, etc. functionalities are mentioned	1.0 / 1.1
Sectoral Application Relevance	Adjustment_Factor3	1.2 for high-value sectors (e.g., pharma, cosmetic); 1.05 for general mentions	1.0 / 1.05 / 1.2
Bioactive Score		**Base_Score × Adjustment_Factor1 × Adjustment_Factor2 × Adjustment_Factor3**	—

In the second step, we assessed whether the functional effects of the bioactive compounds (e.g., antioxidant, antimicrobial, etc.) were clearly stated, and a coefficient of 1.1 was applied to publications containing such functional descriptions. This coefficient ensured that studies reporting not only content but also biological effects were given a higher score.

In the third step, we analyzed whether the compounds included in the publications referenced specific sectoral applications. A coefficient of 1.2 was applied to publications associated with high-value-added sectors such as food, cosmetics, healthcare, functional products, or the pharmaceutical industry. In contrast, a coefficient of 1.05 was applied to other, more general application references—this prioritized content with high sectoral market potential.

In the final step, the scores of the bioactive compounds identified in the articles were multiplied by the correction factors calculated in the first three steps to obtain the Bioactive Score. This score takes into account multidimensional indicators such as the value-added potential of the compound classes reported in the publication, the declaration of functional properties, and sectoral application references.

3.5. Identification of Priority Agricultural Residues Using AHP–TOPSIS

To identify ARs with the highest potential for bioactive compound production using the SFE method, AHP and TOPSIS methods, which are multi-criteria decision-making (MCDM) methods, were employed in conjunction. The AHP method determined the relative weights for decision criteria. In contrast, the TOPSIS method ranked each product-residue pair according to its proximity to the ideal solution in terms of these criteria. Four main criteria were used in the evaluation process: (1) Average available dry residue amount (tons/year) - an indicator of supply size, (2) Coefficient of variation (CV) - a risk measure indicating the level of stability in supply, (3) SFE Score - representing the depth of knowledge and technical applicability of the method in the literature, and (4) Bioactive Score - an indicator of the bioeconomic potential based on the nature, functionality, and market value of the compounds obtained. The calculation methods and formulas for the criteria are summarized in Table 7.

Table 7. AHP-TOPSIS Criteria Calculation Methods and Formulas

Criteria	Description	Applied Formula / Method
DOI_Count	Number of unique studies (DOIs) per product–residue pair	nunique(DOI)
Avg_SFE_Score	Arithmetic mean of SFE scores across all DOIs for each product–residue pair	mean(DOI_SFE_Score)
Avg_Bioactive_Score	Arithmetic mean of Bioactive Scores across all DOIs for each product–residue pair	mean(Bioactive_Score)
Log_DOI_Weight	Weighting coefficient based on literature intensity	log(1 + DOI_Count)
Final SFE Score	Log-weighted average reflecting technical depth of SFE studies	Avg_SFE_Score × Log_DOI_Weight
Final Bioactive Score	Log-weighted average reflecting bioeconomic potential of bioactive compounds	Avg_Bioactive_Score × Log_DOI_Weight
Mean Available Dry Residue	Annual mean dry residue amount (tons/year), estimated via Monte Carlo simulation and weighted across sub-variants	Weighted average of all sub-variants based on production shares
CV (Coefficient of Variation)	Variability level in the simulation outcomes	Standard Deviation / Mean

The first two criteria, namely (1) the average available dry residue amount (tons/year) and (2) CV, are primarily outputs obtained through Monte Carlo simulation. However, for some products (e.g., oranges and apples), TUIK production data are presented as different subvariants of the products (e.g., Jaffa oranges and Navel oranges). In contrast, SFE and bioactive compound studies in the literature are generally conducted using the product's general name. Therefore, before proceeding with the decision analysis, simulation outputs from subvariants within the same primary product category were combined with weighted averages based on their production contribution rates. This resulted in comparable individual available dry residue volume and CV values for each main product-residue pair. This data arrangement enabled the consolidation of values, generated by considering the technical uncertainties associated with the different variants, to be directly integrated into the multi-criteria analysis process.

In contrast, the literature-based indicators (3) SFE Score and (4) Bioactive Score were initially explicitly calculated for each publication. In this context, each publication-based score was grouped under the same product- residue pair, thus aggregating the extent to which each pair has been studied in the literature and the type of information presented in the studies. During this grouping process, for each product- residue pair, (i) the total number of unique publications (DOI_Count), (ii) the average SFE Scores (Avg_SFE_Score), and (iii) the average Bioactive Scores (Avg_Bioactive_Score) were calculated.

However, the presence of numerous publications in the literature for specific product-residue pairs can lead to these pairs appearing more advantageous than others simply due to the number of publications. To avoid this, the average scores calculated for each product- residue pair were not used directly; instead, a logarithmic weighting method was applied.

Within this method, the DOI_Count variable, representing the number of publications, was used for each pair. Logarithmic transformation balances the weights of pairs with very high publication counts, while preserving the contribution of pairs with low publication counts. The coefficient used was calculated using the following formula:

$$Log\_DOI\_Weight = log(1 + DOI\_Count)$$

This coefficient both represents the level of existing literature on the relevant product- residue pair and limits the inflationary effect of the number of publications. Thus, for example, a directly proportional (20-fold) difference between a product-waste pair with 100 articles and a product- residue pair with five articles is not created. The difference is reduced to a more reasonable level through logarithmic transformation.

In the final stage, the SFE Score and Bioactive Score obtained for each product-residue pair were multiplied by this weighting coefficient to calculate weighted average scores. These scores were integrated into the AHP-TOPSIS analysis as final indicators representing both the level of scientific research and the content quality of the product- residue pairs.

In this study, the weights of the decision criteria determined using the AHP method were calculated within the framework of a scenario aimed at prioritizing bioactive compound production potential. In this context, literature-based criteria (SFE Score and Bioactive Score) were given higher priority. In contrast, supply-based criteria (mean available dry residue amount and CV) were considered to support technical potential. The relative importance levels between criteria were defined using a pairwise comparison matrix (a_{ij}). Here, each cell represents the importance level of the row criterion relative to the column criterion. For example, a value of a_{ij} = 3 indicates that the row criterion is "moderately more important" than the column criterion. In contrast, a value of a_{ij}= 1/3 indicates that the row criterion is less important than the column criterion. Due to this structure, the matrix is not symmetric and operates on inverse ratios (a_{ij}= 1 /a_{ji}).

Decision judgments were assigned using Saaty's 1–9 scale. This scale represents "equal importance" with 1, "moderately more important" with 3, "strong importance" with 5, "extreme importance" with 7, and "extreme importance" with 9. Intermediate values (2, 4, 6, 8) are used for intermediate levels of importance.

The pairwise comparison matrix created in the study, based on this logic, is presented in Table 8. For example, the Bioactive Score was assumed to be five times more important than the mean available dry residue, and therefore, the value $a_{Bioactive,Residue}$= 5 was assigned to the relevant cell. Similarly, the SFE score was considered three times more important than the average waste amount and the coefficient of variation. The average waste amount and the CV were assumed to be equally weighted (a = 1). In the final stage, the consistency ratio (CR) was calculated on the resulting matrix, and the logical consistency of the decision judgments was verified by meeting the condition of CR < 0.10.

Table 8. AHP Criteria Comparison Matrix (Value-Added Priority)

Criteria	Mean Available Dry Residue	CV	SFE Score	Bioactive Score
Mean Available Dry Residue	1	1	1/3	1/5
CV	1	1	1/3	1/5
SFE Score	3	3	1	1/3
Bioactive Score	5	5	3	1

The values in the AHP matrix and the criterion weights were obtained using the following general formula. First, each column of the comparison matrix was normalized; then, the weight of the relevant criterion (w_i) was calculated by taking the arithmetic average of the normalized values in each row:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

Here, a_{ij} represents the value in row i and column j in the comparison matrix, and n represents the number of criteria. The CR was also calculated to check the consistency of the matrix. To do this, the maximum eigenvalue (λ_{max}) was estimated by averaging the ratios of the weight vector and the vector obtained by multiplying the relative weight of each criterion by the comparison matrix. The consistency index (CI) and CR were then calculated as follows:

$$CI = (\lambda_{max} - n)/\ n - 1$$

$$CR = CI\ /RI$$

Here, RI is the random consistency index and is a fixed value based on the number of criteria. Since the study had four criteria, a RI of 0.90 was used. A CR value of less than 0.10 indicates that the matrix is consistent. When this condition is met, the calculated weights are integrated into the TOPSIS analysis.

Under the TOPSIS method, a decision matrix containing values corresponding to the four main criteria was prepared for each product-residue pair. This matrix consists of m alternatives (i.e., the number of product-residue pairs) and n criteria (in this case, four criteria). Then, because the criteria were measured on different scales, a normalized decision matrix was created, and a weighted decision matrix was obtained by applying the corresponding weights to the criteria. The normalized value r_{ij} was obtained by dividing the value in each cell by the square root of the sum of the squares of all values in the same criterion column:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

Then, using the criterion weights (w_j) calculated with the AHP method, the normalized matrix was weighted:

$$v_{ij} = w_j\ x\ r_{ij}$$

Ideal (A+) and negative ideal (A-) solution vectors were determined based on this matrix. The first three of the four criteria in the AHP process (mean available dry residue amount, CV, SFE Score, and Bioactive Score) were defined as benefit criteria (J_b); higher values were considered more advantageous. Conversely, the CV, because it is a risk indicator related to supply stability, was considered a cost criterion (J_c), with a lower value being preferred.

$$A^+ = \{\max(v_{ij}) | j \in J_b; \min(v_{ij}) | j \in J_c\}$$
$$A^- = \{\min(v_{ij}) | j \in J_b; \max(v_{ij}) | j \in J_c\}$$

For each alternative, the distances to the positive ideal and negative ideal solutions (S_i^+, S_i^-) were calculated as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^+)^2} \; ; Positive - Ideal$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^-)^2} \; ; Negative - Ideal$$

Finally, the closeness to the ideal solution value (C_i^*) in TOPSIS ranges between 0 and 1, where values closer to 1 indicate higher priority. The product–residue pair with the value closest to 1 was identified as the most preferable alternative. The closeness coefficient is calculated as:

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}$$

Thus, the alternative with the maximum (C_i^*) value is selected as the top-ranked product–residue pair.

3.6. Potential Production and Economic Value Analysis

The potential bioactive compound production quantities and the corresponding economic values for these productions were analyzed for the prioritized product-residue pairs using the AHP-TOPSIS method. The analyses were structured at two levels: (i) determining the theoretical potential for processing all residue and (ii) conducting realistic production-revenue analyses under capacity-limited scenarios.

In the first step, production potentials were calculated based on bulk extract by multiplying the average collectable dry residue quantities previously obtained through Monte Carlo simulation by the SFE efficiencies (% yield) reported in the literature. Yield values were defined for each product-residue pair to correspond to the minimum, median, and maximum scenarios, allowing us to estimate the annual bulk extract quantities (kg/year) that could be obtained under probabilistic pessimistic, base, and optimistic scenarios. Then, scenario-based potential revenue values were calculated using sales prices ($/kg) compiled for each product from literature and market sources. Instead of taking price parameters as constants, they were structured logarithmically, assuming that unit prices would decrease as supply increases. Thus, a more realistic revenue estimate was made, taking into account the impact of market price pressure.

The study included not only bulk extracts but also calculations of specific bioactive compound production and revenue. In these calculations, the specific compound yield (g/kg dry waste) was multiplied by the mean available dry residue amount, resulting in the annual production of the specific compound (kg/year). This amount was then multiplied by the compound-specific logarithmic sales prices, as in bulk extracts, to calculate revenue. Thus, for each product- residue pair, both bulk and specific scenarios were run, and potential production volumes and economic contribution levels were evaluated separately.

Following these theoretical calculations, considering that this potential, calculated assuming full processability, may be limited in practice, integrated SFE facilities with processing capacities of 1,000 tons/year, 10,000 tons/year, and 30,000 tons/year were assumed. Assuming the facilities form an integrated system, it was assumed that the AR types prioritised in the AHP-TOPSIS process are processed within the same system. In this context, monthly processing quotas were defined, taking into account the seasonality of the products, and waste distribution was carried out according to these quotas in each capacity scenario. Thus, realistic production scenarios were created, based not only on theoretical but also on applicable processing capacity. The facility's processing capacity per product was calculated using the following formula:

$$R_{cap} = \sum_{i=1}^{n} \min(R_{i,dry}, K_i)$$

where

K_i: Monthly processing quota defined based on the collection month of the respective product, n: Number of products within the collection period, R_{cap}: Total processable dry residue amount limited by plant capacity

Under these capacity-limited scenarios, production calculations based on both bulk extract and specific compound yields were recalculated, then multiplied by logarithmically calculated unit prices to obtain annual potential revenue values for each capacity level. These outputs not only reflect product- residue -based economic values but also provide input for the macroeconomic impact analysis conducted in the next stage, and were evaluated as final demand shocks for each capacity scenario.

3.7. Macroeconomic Impact Analysis

After calculating the potential bioactive compound production quantities and the corresponding economic values for product-waste pairs prioritized using the AHP-TOPSIS method, input–output (I-O) analysis was applied to estimate the impact of these products on the Turkish economy. In the study, the determined bioactive compound production values were modelled as a final demand shock, and the effects of this shock on sectoral production, value added, and employment were assessed. The analyses were conducted for three target sectors: C10–C12-Food, Beverage, and Tobacco Products Manufacturing; C20-Chemicals and Chemical Products; and C21-Basic Pharmaceutical Products and Pharmaceutical Ingredients.

I-O data were taken from Türkiye's 64-sector I-O table for 2022 (Aşkın, 2023). This table was adapted to 2022 current prices using the 2012 basic I–O table published by TUIK, which employed the RAS method and similar updating techniques. Employment data were obtained from TUIK's sectoral employment statistics, published for the same year, according to the NACE Rev. 2 classification. Policy documents supported by TÜBİTAK-TAGEM and other public institutions have included the production of bioactive compounds among priority products and technologies as of 2022. Therefore, the study considers both data reliability and the sector's development stage, and uses 2022 data as the basis. Output multipliers were derived from the technical coefficient matrix (**A**), which shows the technical relationships between sectors. Based on the intermediate use data in the I-O table, the technical coefficients were calculated relative to the inputs each sector receives from other sectors in its production. A Leontief inverse matrix was then created. This multiplier shows the total production increase that a $1.0 million increase in final demand would create in the economy.

Value-added multipliers were calculated by multiplying the value-added/output ratios for each sector by the output multipliers. For sector i, the value-added multiplier is defined as:

$$VAM_i = \left({}^{VA_i}/_{X_i}\right) \times OM_i$$

where

VAM_i: the value added multiplier of sector i, VA_i: the total value added of sector i, X_i: total output of sector i, OM_i: output multiplier of sector i

The value-added/output ratios were obtained by dividing the value-added vector (row entries of the I-O table) by the corresponding sectoral output values (column totals). These ratios indicate the direct potential for value creation when evaluated through the Leontief inverse matrix (L); the total impact of an increase in final demand, including indirect value-added creation, can be estimated.

Employment multipliers were generated using 2022 NACE Rev.2-based sectoral employment data published by TUIK. Since the I-O table is defined under the CPA 2008 classification, a NACE–CPA concordance was established, and the total number of employees corresponding to each CPA sector was determined. The employment multiplier for sector i was then calculated as:

$$EMPM_i = \left({}^{E_i}/_{X_i}\right) \times OM_i$$

where

$EMPM_i$: the employment multiplier of sector i, E_i: the total employment of sector i,: X_i: total output of sector i, OM_i: output multiplier of sector i

Initially, employment multipliers were expressed as "employee per million TL." However, since the demand shocks applied in the analysis were denominated in foreign currency, these multipliers were converted into "employee per million USD" using the 2022 average exchange rate. This allows the employment effects of final demand shocks to be directly comparable in foreign currency terms.

The final demand vector used in the analysis represents the potential extract revenues estimated in Section 3.6. This shock, when applied to the I-O system, is assumed to be an additional increase in demand on top of the existing final demand in the relevant sectors. Final demand shocks were applied only to the food industry (C10–12), the cosmetics and chemical industry (C20), and the pharmaceutical industry (C21). The final demand vector is therefore defined as follows:

$$Y = [y_{food}, y_{chem}, y_{pharma}]^{-1}$$

where

y_{food}: Annual extract revenue directed to the food sector (\$),y_{chem}: Revenue directed to the cosmetics and chemical sector (\$),y_{pharma}: Revenue directed to the pharmaceutical sector (\$)

This vector was recalculated for each capacity scenario (1,000, 10,000, and 30,000 tons/year), and the following matrix operations were applied for each scenario:

$$\Delta X = L \, x \, Y$$
$$\Delta Value\ Added = v \, x \, \Delta X$$
$$\Delta Employment = e \, x \, \Delta X$$

where

L: Leontief inverse matrix, Y: Final demand shock vector (\$), ΔX:Marjinal production increase arising solely from the demand shock (\$), v: Vector of sectoral value-added multipliers, e: Vector of sectoral employment multipliers (employee/\$)

Thanks to these analyses, not only the production volume but also the magnitude of the economic value added and employment opportunities created by the sector were numerically determined. Thus, the potential contribution of utilizing ARs in the production of bioactive compounds through SFE to the national economy was evaluated from a multidimensional perspective.

CHAPTER 4

DATA SOURCES

4.1. Data Sources for Agricultural Residue Profile

A large amount of quantitative and qualitative data was used to calculate the quantities of field and agro-industrial waste. While field residue was calculated based on direct production volume, agro-industrial residue was derived solely from the portion of production processed in industry. For both waste types, production data, along with technical coefficients such as moisture content, collectability rate, and RPR, are required. A summary of the data types, definitions, units, sources, and areas of use used in the study is presented in Table 9.

Table 9. Summary of Variables Used in Agricultural Residue Estimation

Data Type	Description	Unit	Source	Applies to
Production	Annual production from 2004 to 2024	Ton/year	TUIK	Field & Agro-industrial
Residue to Product	Ratio of field residue mass to main product mass	Unitless (kg/kg)	Literature	Field
Availability	Estimated proportion of residues that can be feasibly collected	%	Literature	Field & Agro-industrial
Moisture	Moisture percentage of the residue, used to calculate dry weight	%	Literature	Field & Agro-industrial
Industrial Processing Ratio	Portion of total production processed by industry	%	Literature	Agro-industrial
Industrial Residue Ratio	Ratio of waste/by-product generated during processing	%	Literature	Agro-industrial
Product Type Aggregation Weights	Used for aggregating variety-level data (e.g., Apple–Granny vs. Golden)	Unitless (share %)	TUIK	Used in normalization

Agricultural production data were obtained at the national level from the Crop Production Statistics database published by TUIK. The data were classified under three main categories: field crops, vegetable crops, and fruit crops. To determine the scope of this study, products in TUIK Crop Production Statistics database were examined in detail, and certain groups were excluded. Of the 204 different agricultural products reported by TUIK, 72 products meeting the criteria below were excluded and not used in analyses. Following the elimination process, field and agro-industrial residues were defined separately for 132 products, consistent with the literature. The excluded groups, along with reasons for their exclusion, are presented in Table 10.

Table 10. Product Groups Excluded from TUIK Dataset and Justifications

Excluded Product Group	Justification
Green fodder crops	Intended for animal feed, not human consumption
Fiber crops (e.g., cotton, flax, hemp)	Industrial usage in textiles, not relevant to food/agricultural residues
Seed production crops	Grown for propagation purposes, not for direct use or processing
Herbs and tea plants (CPA code 01.28)	Low production volumes, specific usage categories
Products under CPA codes 01.11.49 and 01.11.79	Special crop codes with inconsistent or limited production data
Fresh forms of dry legumes	Fresh forms excluded since dry versions were included for residue estimation
Fresh onion and garlic	Excluded due to different storage and processing patterns
Products labeled as "Çerezlik" or "Sofralık"	Consumed directly, not processed industrially; therefore excluded

RPR values were compiled from national sources, including academic publications specific to Türkiye, master's/doctoral theses, TÜBİTAK, and TAGEM projects. For products where appropriate data for Türkiye was not available, FAO technical documents and reports from international organizations such as IEA Bioenergy were used. Minimum and maximum RPR ranges were defined for each product to reflect the uncertainties observed in the literature data. These distributions formed the primary data source for uncertainty analysis in Monte Carlo simulations.

Industrial processing rates were obtained from Ministry of Agriculture projects, sector reports, and academic literature; minimum and maximum ranges were defined for each product. Certain assumptions were also made for product groups. For cereals, a ratio close to 1 was assumed, not because all cereals are industrially processed, but because the majority of their use in Türkiye (e.g., wheat for flour, corn for starch and feed, barley for malt) involves some form of industrial transformation rather than direct household consumption. For pulses, the generally accepted range of 0.35–0.40 reported in sector studies was applied.

However, no industrial waste rate information was available in the literature for some products. In these cases, hypothetical matches were made using similar product groups as references. For example, for fruit and vegetable groups where a precise range of industrial processing ratios cannot be determined on a product-by-product basis, the generally accepted range of 0.35–0.40, as found in industry reports, was adopted. Where direct data was not available, analogous substitutions were applied, such as spinach for leafy vegetables (parsley, arugula, mint), pumpkin for bitter melon, apple for quince and pear, and cranberry for oleaster and jujube. On the other hand, for certain products (e.g., sorghum, millet, flax, canola, rapeseed, sesame, safflower, hemp, poppy, Jerusalem artichoke, salep, mushrooms, and figs), neither direct ratios nor reliable proxies were found. In these cases, the products were excluded from the agro-industrial residue estimation, and thus, no residue amount was calculated for them.

Moisture content is a valid parameter for both field waste and agro-industrial residue. Data were primarily compiled from academic publications, TÜBİTAK projects, university laboratory studies, and sectoral process analyses. Literature reviews revealed that fixed moisture values are generally reported for field residue, while wide ranges are presented for agro-industrial residue. Therefore, a single fixed moisture content was used for each product for field residue, while minimum and maximum ranges were established for agro-industrial residue. In this study, moisture content was divided into three categories, applicable only to agro-industrial residue: low (5–20%), medium (20–75%), and high (75–90%). This classification was based on the water content and drying requirements of the residue and is summarized in Table 11, supported by sample products.

Table 11. Moisture-Based Classification of Agricultural Residues

Category	Moisture Content (%)	Characteristics	Example Residues
Low Moisture	5–20	Requires no or minimal energy for drying.	Wheat bran, hazelnut shells, walnut shells, legume hulls

Table 11. (continued)

Medium Moisture	20–75	Contains primarily bound water; drying may be required but feasible with low energy	Sugar beet pulp, root and tuber vegetables, olive pits, wood-based residues
High Moisture	75–90	Contains high levels of free water; drying requires significant energy input	Fruit and vegetable pulps, citrus peels, tomato pomace, sugarcane bagasse

Source: Havlik et al., 2022

The collectability rate is a valid parameter for both field waste and agro-industrial residue. The data were collected based on findings from residue collection efficiency studies conducted in Türkiye. The literature indicates that the rate of field residue varies depending on factors such as land structure, level of mechanization, and product physiology. In contrast, because agro-industrial residue is generated in more controlled environments, it is observed that the collectability rates for these residue types are more stable. Accordingly, fixed rates widely accepted in the literature were used for field residue, based on the product and type of residue. For agro-industrial residue, a single fixed rate based on common literature values was adopted, without distinguishing between product and residue.

Finally, some agricultural products are reported under more than one variety in the TUIK data structure. For example, apples are listed separately as varieties such as Amasya, Starking, Golden, and Granny Smith. Similarly, many fruit products, such as grapes, oranges, and tangerines, are also classified by type. This detail was particularly taken into account in the AHP-TOPSIS analysis. Because the decision unit in these analyses was defined at the product- residue pair level (e.g., apple-peel), the need for technical scores (e.g., SFE literature score, bioactive score) reduced to the product level for agricultural products defined at the species level became evident.

For this purpose, the average production amount and standard deviation for each species were calculated for the period from 2004 to 2024. Based on these values, the production weight of the relevant species within its product group was determined. The resulting ratios were used in conjunction with the weighted average method to transfer the species-defined scores to the product level. The same method was also applied to recalculate the CV values obtained at the species level and the product level.

It should be emphasized that these species-based weightings were used only in the decision analysis process (e.g., AHP-TOPSIS). No species combinations or weightings were applied in the creation of the AR profile or the Monte Carlo simulations. This is primarily due to significant differences in technical parameters such as RPR, moisture content, and collectability across different types of the same product. These differences were directly integrated into the model on a per-type basis, ensuring that each type was evaluated based on its technical characteristics and maintaining maximum uncertainty in the analyses.

A total of 372 product–residue pairs were initially identified for 132 products in the AW profile. Of these, 87 were excluded from the analysis and the Monte Carlo simulation due to the lack of reliable RPR values in the literature or the absence of other parameters (e.g., moisture, collectability, or industrial processing ratio). Consequently, 285 product–residue pairs corresponding to 124 different products were included in the Monte Carlo simulation. Table 12 summarizes the parameters of these 285 pairs, and the complete list of them is presented in Appendix A. The 87 excluded pairs are not included in the appendix.

Table 12. Distributions of Monte Carlo Simulation Parameters

Parameter Description	Abbreviation	Distribution Type	Applies to	Justification
Production	PROD	Normal / Log-Normal / Gamma / Logistic / Weibull	Field & Agro-industrial	Fitted to 21-year annual historical data using distribution fitting tests; best-fit distribution selected individually for each product.
RPR	RPR_field	Uniform / Beta	Field residues	Mostly reported as min–max intervals without mean/median; fitted to represent uncertainty in crop-to-residue conversion rate.
Industrial Residue Ratio	RPR_ind	Uniform / Beta	Agro-industrial	Literature presents process-specific min–max values; distributions model the potential range of industrial by-products per product unit.
Industrial Processing Ratio	IND	Uniform / Beta	Agro-industrial	Varies by product and year; modeled based on min–max ranges compiled from sectoral and academic sources.

Table 12. (continued)

Moisture	MOIST_field	Constant	Field residues	Literature consistently reports single moisture value per crop; modeled as fixed due to limited variability in field residue conditions.
Moisture	MOIST_ind	Uniform / Beta	Agro-industrial	Moisture levels vary depending on processing methods; modeled using min–max-based distribution fitted per product and waste type.
Availability	AVAIL_field	Constant	Field residues	Generally defined as a fixed recovery efficiency based on mechanization and terrain; constant rate assumed for all crops.
Availability	AVAIL_ind	Constant	Agro-industrial	Industrial residues are assumed to be nearly fully recoverable; constant availability value adopted from literature benchmarks.

4.2. Data Sources for Bioactive Ingredients and SFE Applications

A systematic literature search was conducted for 124 agricultural products included in the Monte Carlo process. During this process, products with a variety of species were first deduplicated; for example, varieties such as apples (Amasya, Golden, Granny Smith) or grapes (seeded, seedless) were combined at the product level. Consequently, literature searches for 99 products were conducted using a standard nomenclature.

The literature search process utilized international databases, including Web of Science, Scopus, PubMed, ScienceDirect, and Springer Nature. Keywords such as "SFE," "SC-CO_2," and "SCFE," along with various combinations of these, were used in the searches, along with each product name, to describe SFE processes. The query structures used are shown in Table 13.

Table 13. Search Queries by Database

Database	Search Query
Scopus	TITLE-ABS-KEY(("supercritical carbon dioxide" OR "SCFE" OR "SC-CO2" OR "supercritical fluid extraction") AND "<product name>")
Web of Science	TS=(("supercritical carbon dioxide" OR "SCFE" OR "SC-CO2" OR "supercritical fluid extraction") AND "<product name>")
PubMed, Science Direct, Springer Nature	("supercritical carbon dioxide" OR "SCFE" OR "SC-CO2" OR "supercritical fluid extraction") AND ("<product name>")

A total of 4270 articles were collected from the databases across 99 different products. These studies were systematically filtered according to the methodological approach described in section 3.3. Details regarding the applied filtering process are presented in Table 14.

Table 14. Overview of Literature Screening and Selection Process

Processing Stage	Description	Number of Records
Initial retrieval	Total number of records obtained from multiple databases using defined queries	4270
After deduplication	Unique records remaining after removing duplicates based on title and DOI	2530
Excluded due to missing product-residue identification	Records where no valid product + residue pair could be detected via text mining	1610 (excluded)
Retained after residue identification	Records with at least one product + residue match (Residue_Flag > 0)	920
Excluded after manual verification	Records removed due to incorrect or misleading residue mentions	130 (excluded)
Final set of eligible articles for SFE and bioactive scoring	High-confidence records used for further content analysis and scoring	790

The 790 articles obtained after filtering were examined in detail, not only in terms of product and residue types but also in terms of technical and functional parameters of the SFE processes. The full text of each study was analyzed, and process variables, including the type of solvent used, temperature and pressure values, extraction time, solvent-to-feed ratio, and flow rate, were systematically recorded. Furthermore, the reported extract yield, bioactive compounds obtained, the functional properties of these compounds, and their sectoral application areas were also included in the data set. For studies with an economic content, information on commercial value, scale of application, and cost analyses was also collected. Detailed information on the data collected from the articles is presented in Table 15.

Table 15. Structured Parameters Extracted and Derived from Literature Analysis

Parameter	Description	Data Source
Product	Name of the agricultural product used in the SFE study	Original from article
Residue Type	Specific agricultural residue used (e.g., seed, husk, peel)	Original from article / Text mining
Extraction Type	Type of SFE process (e.g., SC-CO_2, SC-CO_2 + ethanol)	Original from article

Table 15. (continued)

SFE_Flag	Binary flag indicating whether SFE-related process parameters are reported	Derived from parameter availability
Temperature	Operating temperature used during extraction	Original from article
Pressure	Operating pressure used during extraction	Original from article
Extraction Time	Duration of extraction process	Original from article
S/F Ratio	Solvent-to-feed ratio (e.g., CO_2-to-residue mass ratio)	Original from article
Flow Rate	Solvent (e.g., CO_2) flow rate used during extraction	Original from article
Parameter_Flag	Binary flag indicating whether all core process parameters are available	Derived from parameter availability
Yield	Extract amount obtained from raw material, typically in % or mg/g	Original from article
Yield_Flag	Binary flag indicating whether yield data is available	Derived from article
Bioactive Compounds	Specific compounds identified in the extract (e.g., quercetin, limonene)	Original from article
Bioactive Class	General class of compounds (e.g., phenolics, flavonoids, fatty acids, terpenes)	Derived from Bioactive Compounds
Functionality Reported	Functional roles reported (e.g., antioxidant, antimicrobial, anti-inflammatory)	Original from article
Sectoral Application	Application domains directly mentioned in the study (e.g., food, pharma)	Original from article
Sectors	Standardized sectors (e.g., Food, Cosmetic, Pharmaceutical, Agriculture, Other)	Derived from Sectoral Application
Scale of Study	Scale of the experiment (e.g., lab-scale, pilot-scale, industrial-scale)	Original from article
Economic Insight	Any economic insight: cost, yield-price relation, market relevance, etc.	Original from article

4.3. Data Sources for Revenue Calcuation

In the AHP-TOPSIS process, the unit prices for selected ARs were primarily investigated in the literature. Price data were classified into three different groups based on the nature of the extract, and each price was assigned a "Price_Flag" value.

Table 16. Classification of Extract Price Data Used in Revenue Estimation

Price_Flag	Description	Data Source	Indicative Use in Analysis
0	Prices of individual bioactive compounds found in literature	Literature, Tridge	Supplementary – specific compound-level estimation
1	Bulk extract prices reported in literature (e.g., $/kg of extract)	Literature, Tridge	Primary scenario – realistic market prices
2	Laboratory-scale prices from suppliers (e.g., Sigma-Aldrich, high-purity)	SigmaAldrich	Reference only – high uncertainty

Details regarding the classification are presented in Table 16. To ensure comparability of price data, all price data obtained from different sources were converted to USD. This conversion used the reference exchange rate of 1 EUR = 1.18 USD for the Euro and 1 NZD = 0.60 USD for the New Zealand Dollar. Minimum and maximum price ranges were established for each type of AR and its corresponding extract.

4.4. Data Sources for Macroeconomic-Impact Analysis

The key parameters defined for each product-residue-component combination in the macroeconomic assessment process based on I-O analysis, and the data sources from which these parameters were obtained, are summarized in Table 17.

Table 17. Key Data Used in Input–Output Based Macroeconomic Impact Assessment

Parameter	Description	Data Source
Sector	Economic sector in which the extract is utilized (e.g., Food, Pharma, Chemicals)	Derived from sectoral application in SFE literature (See Table 15)
Demand Shock (USD)	Projected extract-based revenue allocated to target sectors	Estimated from product + residue-based revenue outputs (Section 3.6)
I-O Table	National input–output matrix used in the analysis	64-sector I-O table for Türkiye, updated to 2022 using RAS method (Aşkın, 2023)
Output Multiplier	Total economic output generated per unit of final demand	Calculated from 2022 I-O table and Leontief inverse matrix
Employment Multiplier	Number of jobs created per million USD of final demand	Derived from 2022 labor statistics (TUIK), converted from person/million TL to person/million USD
Value Added Multiplier	GDP contribution generated per unit of final demand	Computed using value-added/output ratios and Leontief inverse matrix (2022 I-O table)

The Sector parameter identifies the primary sector in which the relevant extract is economically evaluated. This mapping was made according to sectoral practices reported in the literature, with each component assigned to one of the C10-12, C20, or C21. The demand shock represents the annual potential extract revenue calculated on a scenario basis for each product-residue combination. This revenue was modelled as additional final demand directed to the relevant sector and was considered as a demand shock vector component in the I-O analysis.

I-O data are based on the 2022 I-O table for the Turkish economy. The table was updated using the RAS method, based on the 2012 basic I-O data published by TUIK

(Aşkın, 2023), and restructured at the 64-sector level. The data in the table was used to generate the Leontief inverse matrix, and the output multiplier and value-added multiplier were calculated.

Employment data were obtained from TUIK’s 2022 "Labor Force Statistics" dataset. This dataset encompasses 87 sectors, classified according to the NACE Rev. 2 classification, and presents the number of employees in annual averages. However, because the sector classification used in the I-O analysis is at the 64-sector level according to the CPA 2008 coding, a NACE-CPA mapping was performed to ensure data compatibility. The employment size in each NACE sector was transferred to the corresponding CPA sector, and the total number of employees was determined only for the three target sectors (C10-12, C20, C21) within the scope of the analysis. Employment coefficients were calculated in empleyee/million TL by dividing these employee numbers by the total output of each sector in the I-O table. Finally, because the demand shocks used in the analysis were denominated in foreign currency, these coefficients were converted to people/million USD based on the 2022 average exchange rate.

CHAPTER 5

RESULTS

5.1. Agricultural Residue Profile

The AR profile was obtained using a Monte Carlo simulation that incorporated uncertainties in the parameters. In this context, the parameter distributions to be used in the study were first analyzed on a product- residue basis. Sensitivity tests were then conducted to determine the optimal number of simulations to use in the study.

Parametric distribution tests were applied to the annual production amounts of agricultural products for the period from 2000 to 2024. Five different distribution functions were used: normal, log-normal, gamma, logistic, and Weibull. The most appropriate distribution for each agricultural product was selected based on probability density functions and statistical criteria, including the S-W, A-D, and K–S tests. Thus, during the simulation process, production quantities were generated based on specific distribution functions defined for each product, rather than deterministic fixed values. For agricultural products where production data was insufficient ($n < 5$), empirical data was used. The distribution types of agricultural product production are shown in Table 18.

According to Table 18, the findings indicate that the log-normal distribution is the most commonly used type, accounting for approximately 60% of all products. For approximately 38% of the products, the gamma, logistic, and Weibull distributions were found to be suitable for modelling. For the remaining 2%, the empirical data was used due to the small number of data points. To support the evaluation of distribution types, scatter plots were created for agricultural production data. For each graph, the distribution type was visualized by fitting a probability density function (PDF) to a histogram of the product's historical production data. The graph descriptions include the parameters of the distribution used and the fit criteria. A sample output of the five different distribution types evaluated within the analysis is presented in Figure 3; scatter plots for all 132 agricultural products included in the study are included in Appendix B.

Table 18. Distribution Types of Production Data based on Product

Production Distribution	Product Count	Products
Empirical Data	2	Pumpkins,Squash and Gourds-Bitter Melon, Other Edible Roots and Tubers-Salep
Gamma Distribution	9	Avocados, Lemons and Limes, Tangarines, mandarins, clementines-Other, Loquat, Lettuce and Chicory-Curly, Other Leafy or Stem Vegetables-Parsley, Cucumbers and Gherkins-Cucumber, Eggplants, Pumpkins,Squash and Gourds-Squash
Log-Normal Distribution	81	Grapes-Seeded,for Drying, Grapes-Seedless,for Drying, Figs, Pomelos and Grapefruits, Oranges-Washington, Oranges-Other, Tangarines, mandarins, clementines-Satsuma, Tangarines, mandarins, clementines-Klemantin, Other Citrus Fruits, Apples-Golden, Apples-Starking, Apples-Granny Smith, Apples-Other, Pears, Quinces, Cherries, Peaches, Nectarines, Plums, Other Pome Fruits and Stone Fruits-Cornelian Cherry, Other Pome Fruits and Stone Fruits-Oleaster, Other Pome Fruits and Stone Fruits-Jujube, Kiwi Fruit, Strawberries, Almonds, Chestnuts, Hazelnuts, Pistachios, Walnuts, Other Tree and Bush Fruits-Persimmon, Olives-Olive Oil, Tea-Leaves, Beans-Green, Kidney Beans-Green, Other Green Leguminous Vegetables-Cow Pea, Other Green Leguminous Vegetables-Broad Beans, Asparagus, Cabbages-Brussels Sprouts, Cauliflowers, Broccoli, Lettuce and Chicory-Head, Spinach, Artichokes, Other Leafy or Stem Vegetables-Celery, Other Leafy or Stem Vegetables-Chards, Other Leafy or Stem Vegetables-Purslane, Other Leafy or Stem Vegetables-Rocket, Other Leafy or Stem Vegetables-Mint, Other Leafy or Stem Vegetables-Dill, Chilles and Peppers-Paprika, Chilles and Peppers-Stuffing, Chilles and Peppers-Charleston, Cucumbers and Gherkins-Gherkins, Tomatoes,Production, Other Fruit-Bearing Vegetables-Okra, Other Tropical and Subtropical Fruits-Pepino, Carrots and Turnips-Carrots, Garlic-Dry, Onions-Dry, Other Root, Bulb or Tuberous Vegetables-Horseradish, Other Root, Bulb or Tuberous Vegetables-Red Radish, Mushrooms and Truffles, Wheat-Durum, Wheat-Other, Maize, Barley-Beer, Barley-Other, Rye, Oats, Chick Peas-Dry, Lentils-Dry,Green, Groundnuts-In Shell, Seed-Lin, Seed-Sesame, Seed-Sunflower,Oil Production, Seed-Hemp, Seed-Poppy, Potatoes, Sugar Beet, Sugar Beet Seeds, Tobacco-Unmanufactured
Logistic Distribution	11	Grapes-Wine industry, Oranges-Navel, Tangarines, mandarins, clementines-King, Apples-Amasya, Sour Cherries, Raspberries, Other Tree and Bush Fruits-Locust Bean, Pumpkins,Squash and Gourds-Pumpkin, Other Root, Bulb or Tuberous Vegetables-Beetroot, Sorghum, Millet

Table 18. (continued)

Normal Distribution	14	Apricots, Apricots-Wild, Other Tree and Bush Fruits-Pomegranate, Peas-Green, Cabbages-Red, Cabbages-Black, Lettuce and Chicory-Iceberg, Cantaloupes and Other Melons, Chilles and Peppers-Thin Tapered, Leeks and Other Alliaceous Vegetables-Leek, Other Root, Bulb or Tuberous Vegetables-White Radish, Lentils-Dry,Red, Seed-Safflower Seed, Sugar Cane
Weibull Distribution	15	Bananas and Plantains, Other Berries-Blueberry, Other Berries-Blackberry, Other Berries-Mulberry, Other Tree and Bush Fruits-Medlar, Cabbages-White, Other Leafy or Stem Vegetables-Cress, Watermelons, Carrots and Turnips-Turnips, Other Root, Bulb or Tuberous Vegetables-Celeriac, Soya Beans, Seed-Rape and Colza, Rice-Not Husked, Potatoes-Sweet, Other Edible Roots and Tubers-Jerusalem Artichokes

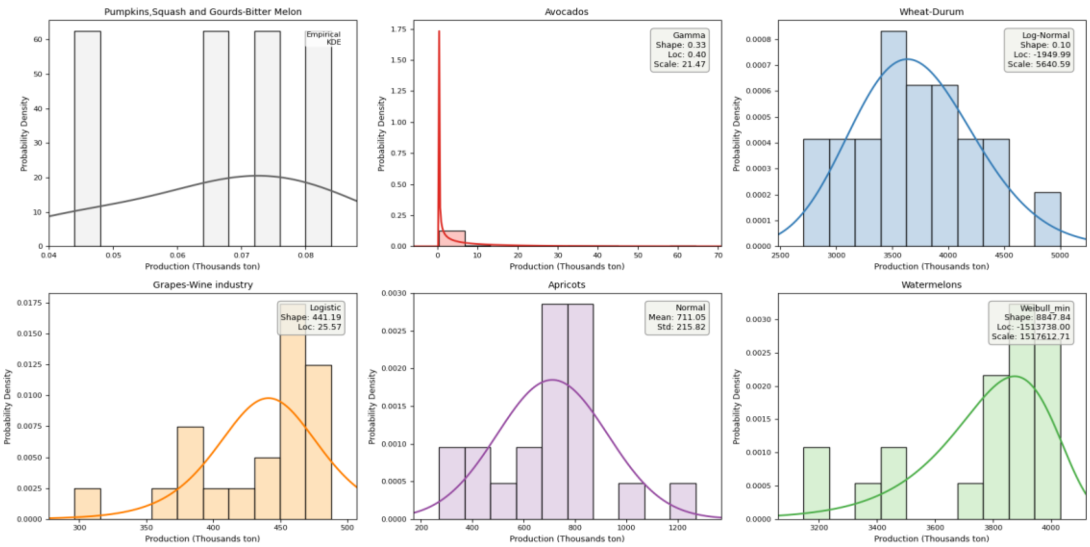

Figure 3. Fitted Production Distributions of Selected Product

For parameters other than agricultural production data, uniform and beta distributions were evaluated based on the minimum and maximum values reported in the literature. The choice between the two distributions depended on the characteristics of the available data. When only minimum and maximum values were reported and no information about the probability density was available, a uniform distribution was employed, assuming that all values within the range were equally likely. In contrast, when parameter values exhibited an asymmetric structure or low variance around a mean, the beta distribution was preferred, as it allows greater flexibility to represent skewed distributions within a bounded range (0–1). Accordingly, ratio variables representing physical components, such as the RPR and industrial residue ratio, were generally modelled with uniform distributions.

In contrast, parameters such as moisture content (which was assumed to be constant only for field residues) and specific product-specific industrial processing rates were represented using beta distributions to capture their asymmetric tendencies better. The collectability ratio was assumed to be a constant value. The distribution types for these parameters are listed in Table 19.

Table 19. Distribution of Other Parameters

Parameter	Beta	Uniform	Constant	Total
Availability (Agro-Industrial)	0	0	285	285
Availability (Field)	0	0	285	285
Industry Processing Rate (Agro-Industrial)	151	134	0	285
Moisture Content (Agro-Industrial)	189	96	0	285
Moisture Content (Field)	0	0	285	285
RPR (Agro-Industrial)	121	164	0	285
RPR (Field)	70	215	0	285

The findings showed that the RPR parameter used for agro-industrial residues was more frequently modelled with a beta distribution compared to field residues. This suggests that the RPR parameter has a more skewed or narrow distribution structure in agro-industrial residues. Similarly, the moisture content of agro-industrial residues was predominantly modelled with a beta distribution, while the moisture content in field residues was assumed to be a constant value. Parameter distributions determined on a product-by-product basis were used in Monte Carlo simulations. To establish an accurate and stable AR profile, a sensitivity analysis was conducted using Monte Carlo simulations corresponding to different iteration numbers (500, 1000, 2000, 5000, 6000, and 10000). For each set of iterations, the average amount of available dry residue was calculated, and absolute differences and percentage changes were compared between successive iterations. The optimum iterations obtained for all combinations were analyzed, and a standard iteration threshold was determined that provided sufficient accuracy for more than 90% of the products, with the percentage difference falling below 1%. The results of the sensitivity analysis are presented in Table 20.

Table 20. Sensitivity Analysis of Monte Carlo Simulation Across Iteration Scenarios

Compared Simulation	Change in Mean Available Dry Residue (ton)	Percent Change (%)
500 vs 1000	1,275.92	1.95
1000 vs 2000	967.70	1.50

Table 20. (continued)

2000 vs 5000	643.24	1.00
5000 vs 6000	372.74	0.73
6000 vs 10000	372.65	0.61

The findings indicate that 6000 iterations provided sufficient accuracy and stability for the AR profile, which contains 132 different products. In this context, a Monte Carlo simulation was conducted over 6000 iterations, yielding the AR profile for Türkiye. In the AR profile, four key waste metrics were calculated for each product-residue combination: theoretical residue, theoretical available residue, theoretical dry residue, and available dry residue. Standard deviations were also obtained for each. The results are presented in Table 21.

Table 21. Summary of Agricultural Residue Profile

Parameter	Agro-Industry	Field	Total
Number of Products	109	81	132 (Distinct)
Theoretical Residue (Million tons)	23.04	82.23	105.27
Std. Dev. (Theoretical Residue) (Million tons)	0.11	0.61	–
Theoretical Dry Residue (Million tons)	16.40	53.83	70.23
Std. Dev. (Theoretical Dry Residue) (Million tons)	0.09	0.44	–
Available Residue (Million tons)	18.43	30.85	49.28
Std. Dev. (Available Residue) (Million tons)	0.08	0.17	–
Available Dry Residue (Million tons)	13.12	16.38	29.50
Std. Dev. (Available Dry Residue) (Million tons)	0.07	0.09	–

According to Table 21, the findings indicate that Türkiye's AR profile contains approximately 50 million tons of available residue, of which approximately 30 million tons is equivalent to dry residue. Approximately 45% of the available dry residue originates from agro-industrial sources, while the remainder originates from the field.

To examine the product-based distribution of AR, the top 10 residue-producing crops in the field and agro-industrial residue were examined. An examination of the field-generated residues in Figure 4 reveals that cereal crops such as wheat, corn, and barley, which have high production volumes and extensive cultivation areas, are among the most common residue types in this category. This suggests that field-generated residues primarily originate from crops grown on large areas and generate high-volume byproducts such as straw and bran.

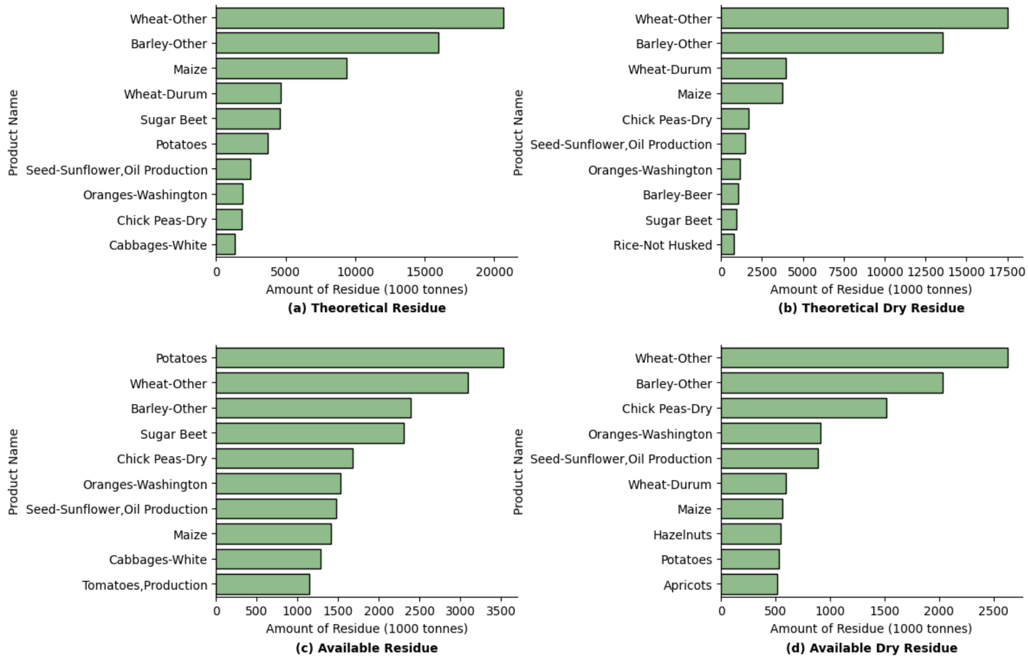

Figure 4. Top 10 Products in Field Residue Profile

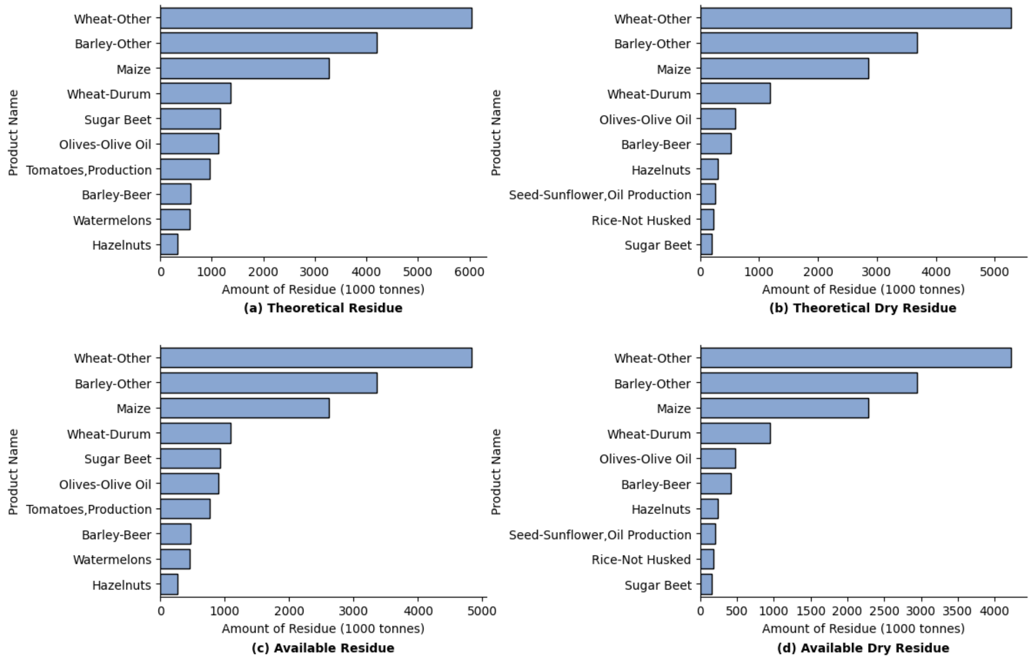

Figure 5. Top 10 Products in Agro-Industrial Residue Profile

In the agro-industrial residues shown in Figure 5, the most prominent crops are those with a high processing rate and a high level of industry dependence. Similar to field residues, wheat, barley, and corn products dominate the residue profile, while fruits and vegetables, such as olives, tomatoes, and watermelons, stand out due to their high residue density. The findings reveal that agro-industrial residues are concentrated primarily around processed products, and that the relationship with industry is a determining factor in this residue profile.

To assess the impact of parameter uncertainties on AR volumes, CV was calculated for each product–residue pair. CV calculations were carried out at two levels: (i) parameter-specific CVs (production volume, RPR, moisture content, and collectability ratio), which identify the primary sources of uncertainty, and (ii) the overall CV of available dry residue, which captures the combined effect of all parameters on the final waste estimate. The overall CV was obtained directly from the Monte Carlo simulation results of dry residue volumes, while parameter-specific CVs were used to interpret which variables contributed most to variability.

Table 22 presents the results for selected products (wheat, barley, corn, and olives), comparing field and agro-industrial residues as illustrated in Figures 4 and 5. The results indicate that, particularly for agro-industrial residues, variability in moisture content and processing-related parameters significantly increases the CV. For example, in wheat, the moisture content CV exceeds 20% for husk and bran residues, leading to higher uncertainty in final waste estimates. Conversely, for field residues, the variability is mainly driven by the RPR and production volume. Especially for crops such as corn and olives, high CVs in production volume reduce the predictability of the overall waste amount. Detailed CV values for all product–residue pairs are provided in Appendix C.

To visualize the relationships between the data, the distribution between the CV of dry available residue and the CV of other parameters is presented in Figures 6 and 7. Outliers with CVs above 150% are highlighted by labelling.The distribution patterns observed in the graphs provide important insights into the structure of parameter uncertainties. In Figure 6, the relationship between production volume and dry residue shows a largely linear trend, indicating that production is the primary driver of residue quantities. In contrast, the relationship between RPR and dry residue is more scattered, reflecting the high variability of RPR values across products and their strong dependence on product-specific characteristics rather than constant coefficients.

Table 22. CV Analysis for Selected Products

Product Name	Residue Source	Residue Type	CV (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source
Wheat-Other	Field	Straw	20.92	6.46	19.85	Constant	Constant	-	RPR
Maize	Field	Stalk	35.56	29.42	19.48	Constant	Constant	-	PROD
Barley-Other	Field	Straw	15.62	14.01	6.81	Constant	Constant	-	PROD
Barley-Other	Field	Stalk	15.88	13.83	7.70	Constant	Constant	-	PROD
Olives-Olive Oil	Field	Prunings	42.77	35.20	23.66	Constant	Constant	-	PROD
Wheat-Other	Agro-Industry	Husk	8.69	6.61	4.71	19.85	Constant	Constant	MOIST
Wheat-Other	Agro-Industry	Bran	12.77	6.61	10.51	20.11	Constant	Constant	MOIST
Maize	Agro-Industry	Husk	32.92	29.64	13.37	19.87	Constant	Constant	PROD
Maize	Agro-Industry	Cob	40.42	29.63	25.89	20.06	Constant	Constant	PROD
Barley-Other	Agro-Industry	Husk	21.44	13.91	15.86	20.01	Constant	Constant	MOIST
Barley-Other	Agro-Industry	Bran	22.49	13.76	17.74	19.95	Constant	Constant	MOIST
Olives-Olive Oil	Agro-Industry	Peel	38.77	34.26	Constant	19.38	Constant	Constant	PROD
Olives-Olive Oil	Agro-Industry	Seed	45.34	35.32	20.35	19.29	Constant	Constant	PROD
Olives-Olive Oil	Agro-Industry	Pulp	42.59	35.94	11.06	19.57	Constant	Constant	PROD

Moisture content, on the other hand, is typically reported within narrow ranges or fixed values in the literature, which explains the clustering observed in specific regions of the graph. The only notable outlier in the graph is the product "Seed Hemp-Stem,Leave," which stands out from all other products with a variance of over 200%.

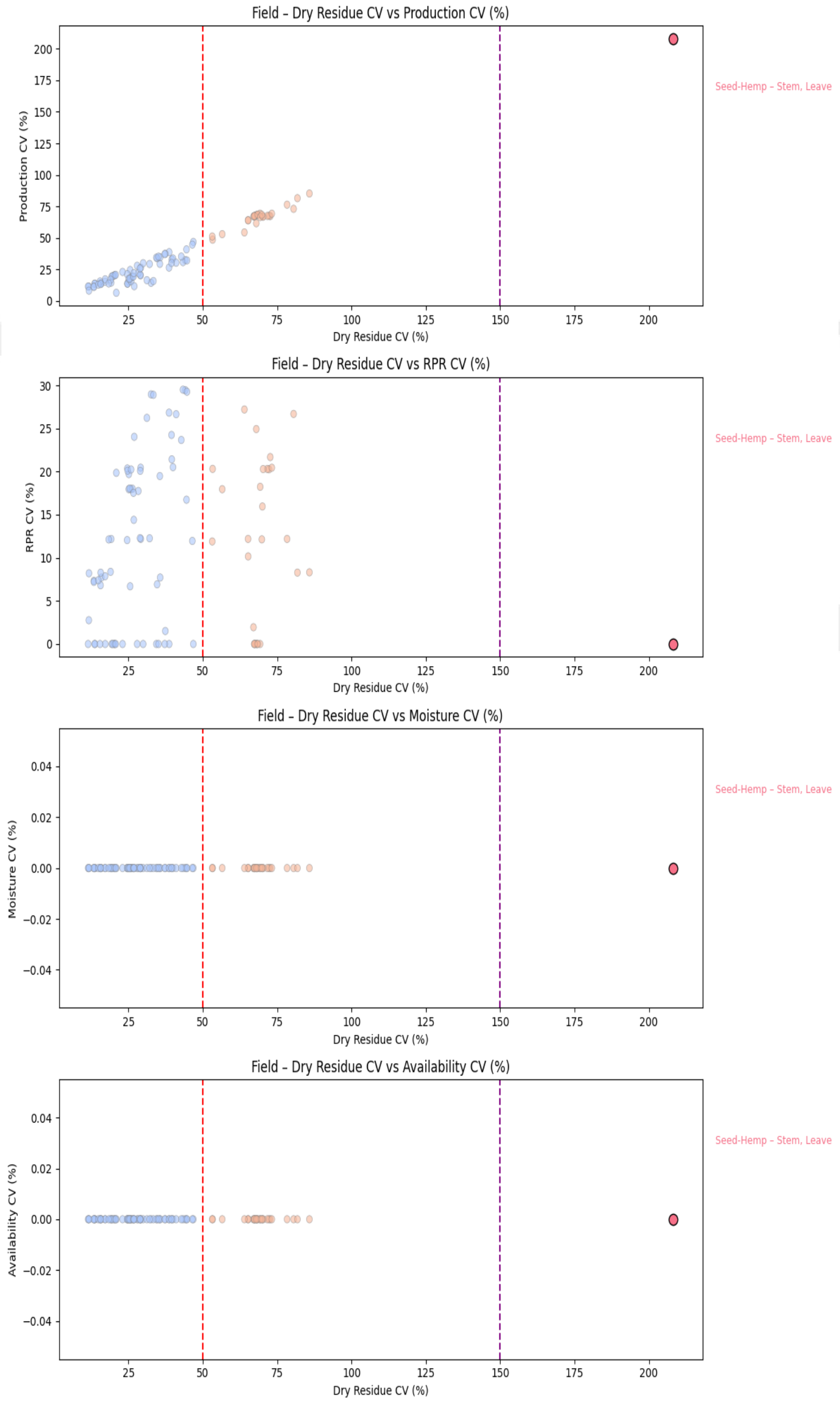

Figure 6. Distribution Plots of Parameters' CV in Field Residue Profile

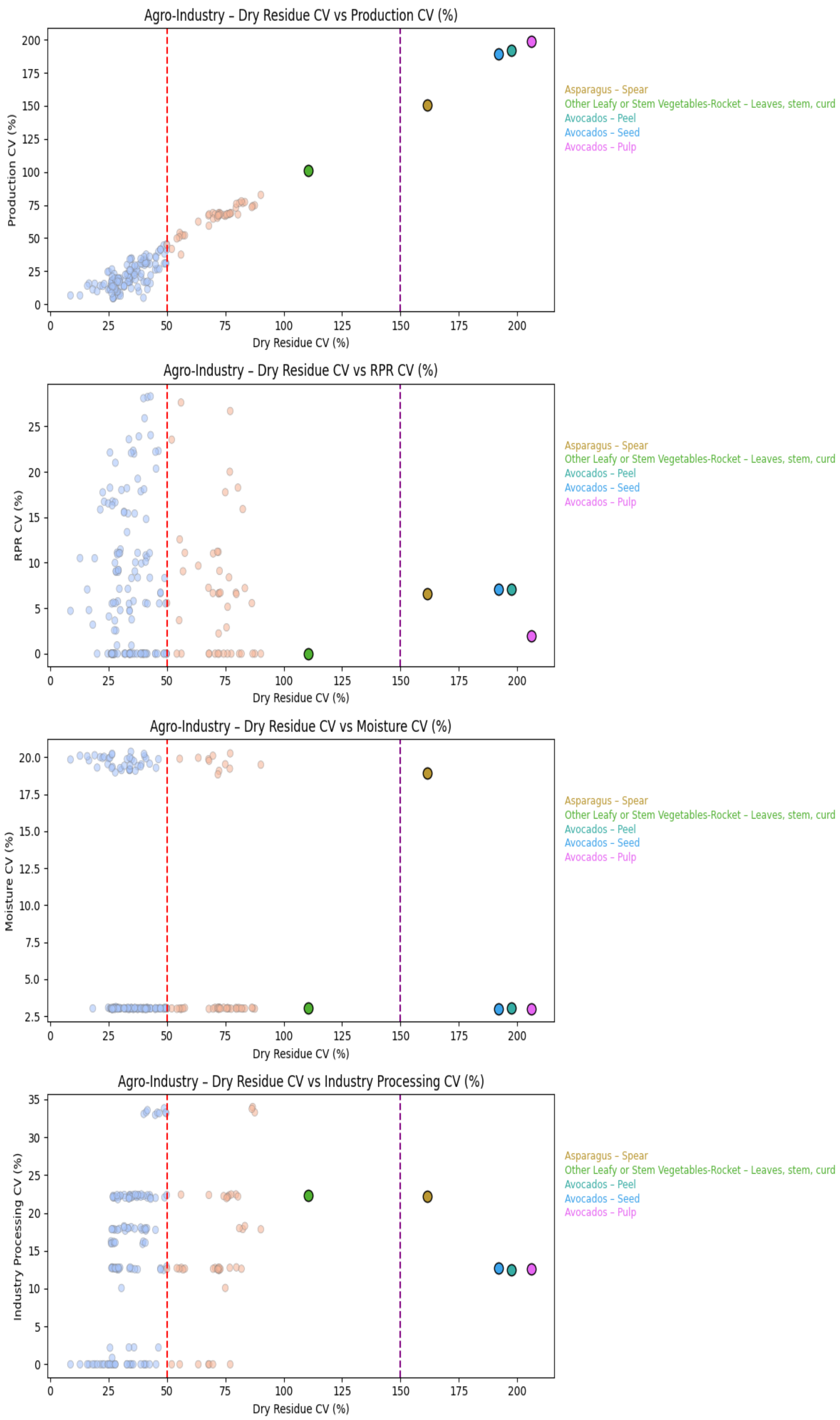

Figure 7. Distribution Plots of Parameters' CV in Agro-Industrial Residue Profile

In Figure 7, the distribution of agro-industrial residues reveals a more dispersed structure compared to field residues, as moisture content and industrial processing rates also contribute to the uncertainty, in addition to production and RPR. This leads to a broader and less regular distribution. For certain products, such as avocado and rocket, the high variance in these parameters results in CV values exceeding 150% for dry residues. These findings highlight that the relationships among parameters are not homogeneous and that uncertainty levels are substantially higher for certain product groups.

To quantify the relationships between the data, the relationship between dry available residue and the parameters was examined using Spearman correlation analysis. The results of the correlation analysis are presented in Figure 8.

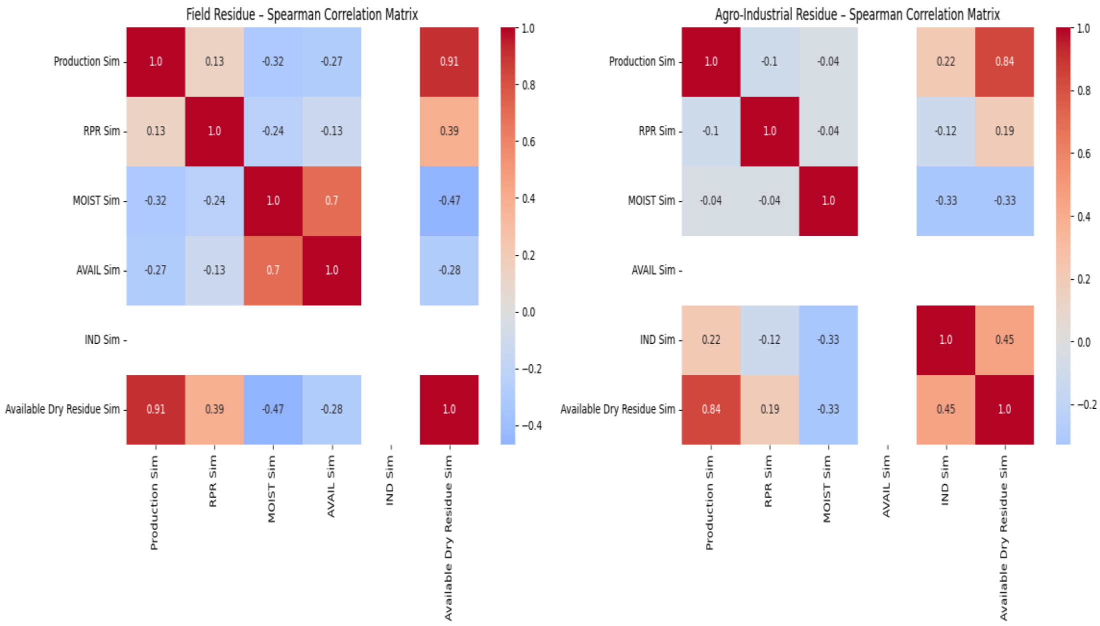

Figure 8. Spearman Correlation Matrix of Parameters

The results in the correlation matrix show that production and RPR in field residue, as well as production and moisture content in agro-industrial residue, are significantly correlated with available dry residue. Overall, the parameter contributing the most to the overall uncertainty in Türkiye's AR profile stems from the variance in production data.

5.2. Literature Review, SFE and Bioactive Score Analysis

The 132 agricultural products included in the AR profile were classified at the species level and reduced to 99 different primary product categories (See Section 4.2). These products were evaluated by the systematic literature review steps described in Section 3.3; only 790 articles with clearly defined product-residue pairs were included in the detailed analysis (See Table 14). The product-based distribution of the articles is presented in Figure 9, while the distribution of AW types included in the articles is presented in Figure 10.

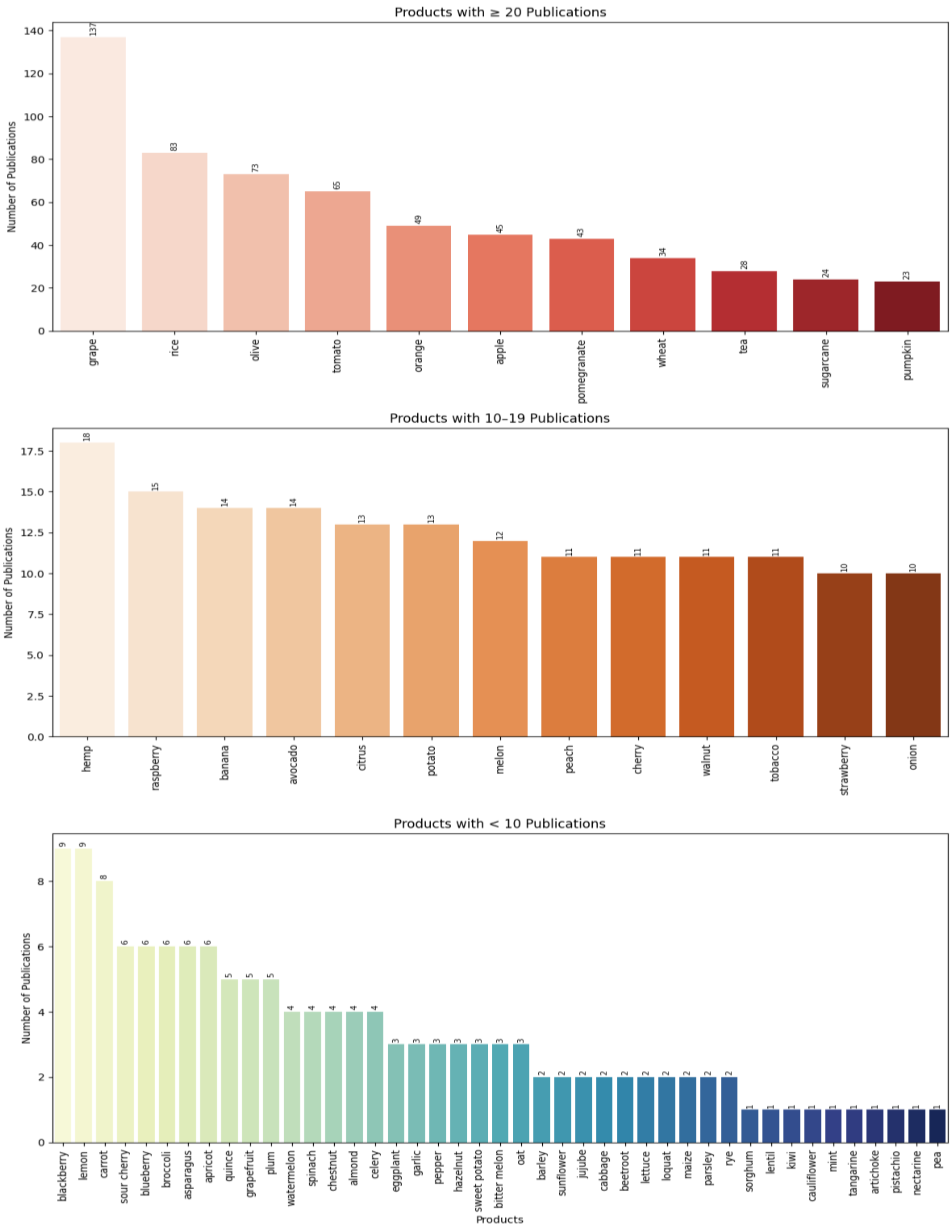

Figure 9. Distribution of DOI’s based on Agricultural Product

The findings in Figure 9 show that the 790 articles are distributed across 67 agricultural products, and 32 products do not contain any comprehensive studies on AR-SFE. The findings in Figure 9 indicate that grapes, rice, olives, tomatoes, and oranges are the five most studied agricultural products in the SFE literature. The findings in Figure 10 show that the 790 articles are distributed across 124 different types of AR, with the AW types most prominent in the literature being predominantly of agro-industrial origin. The findings indicate that grape (pulp and seeds), rice (bran), tomato (pulp), and orange (peel) waste are the five most frequently studied ARs in the SFE literature.

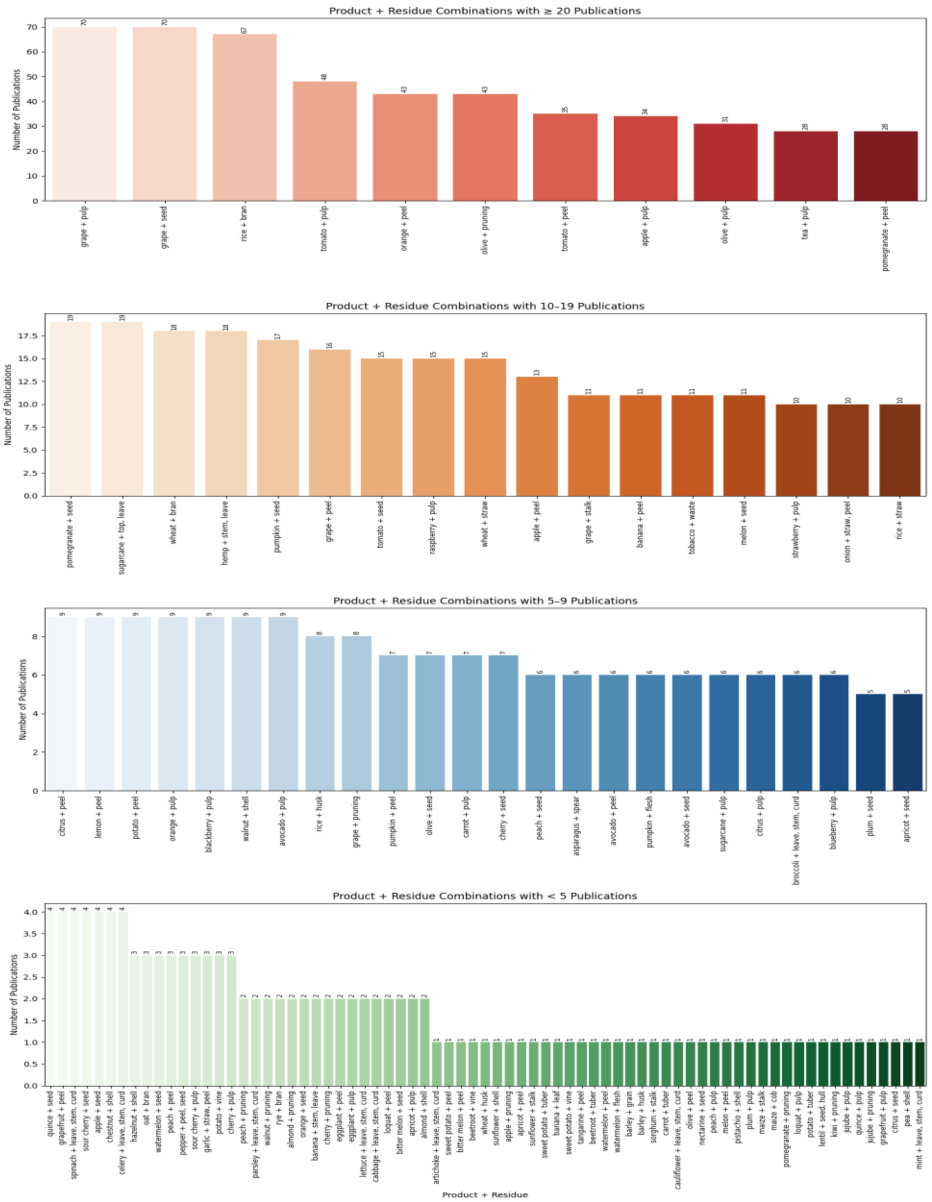

Figure 10. Distribution of DOI's based on Agricultural Residue

For each AR type, the scores obtained through the SFE Score generation process in Section 3.4 and the number of publications in the SFE literature were compared (see Table 5). In Figure 11, the horizontal axis displays the SFE Score (0–4), and the vertical axis displays the number of unique publications (DOI). Each bubble represents a product+waste pair, and the bubble color indicates the presence of SFE parameter data (SFE_Flag: 0 = no data, 1 = complete data); the bubble size is proportional to the number of publications in the literature. The findings indicate that some ARs, despite having a high number of publications, are represented by relatively low SFE Scores. This suggests that while these publications primarily employ the SFE method, the parameter and/or yield information is not sufficiently detailed and sufficient scientific depth is not provided. For example, while the combinations "grape-pulp" and "grape-seed" have the highest number of publications, the bubble colors indicate that some publications for these pairs lack parameters. Similarly, for product-residue pairs such as "olive-pulp" or "orange-peel," despite a relatively high number of publications, the bubble colours remain grey, and the density of studies lacking parameter and/or yield data is high.

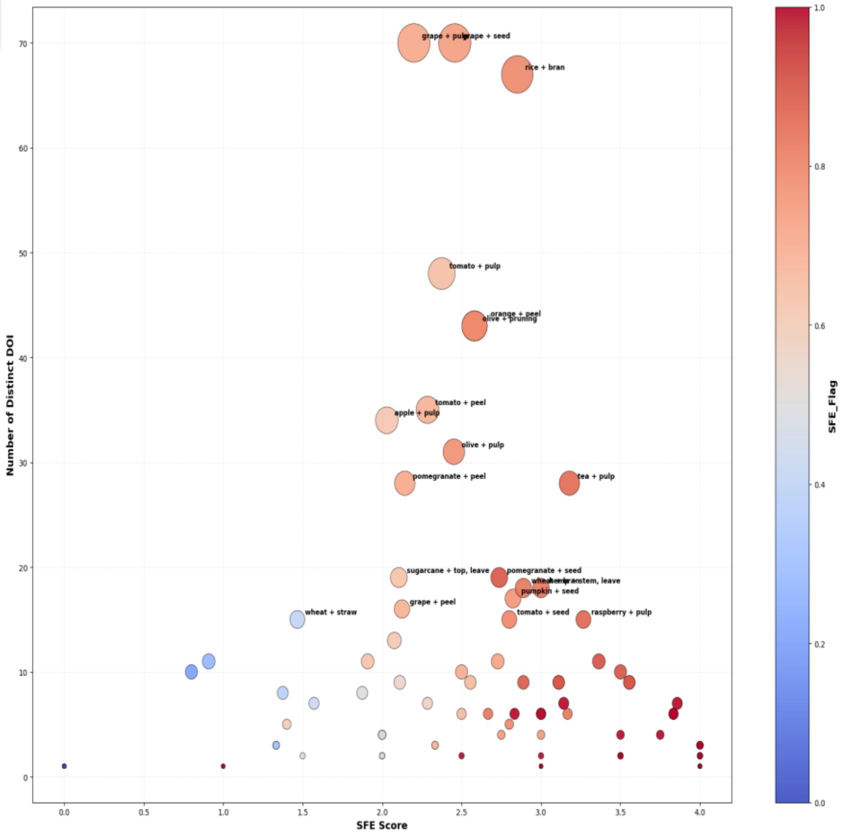

Figure 11. SFE Score vs DOI Instensity Bubble Chart

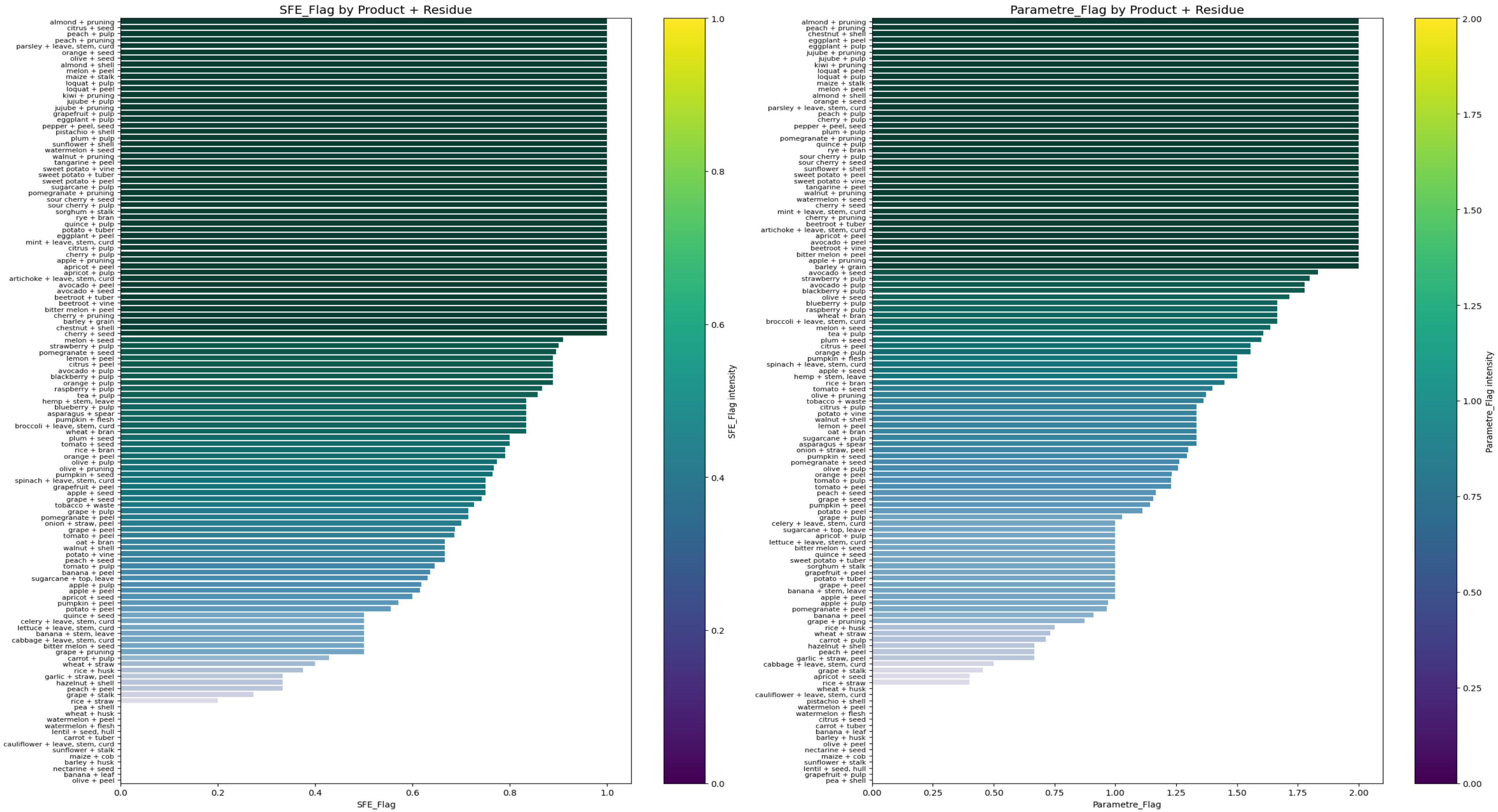

Figure 12. Detailed Parameter of SFE Score-SFE_Flag and Parameter_Flag

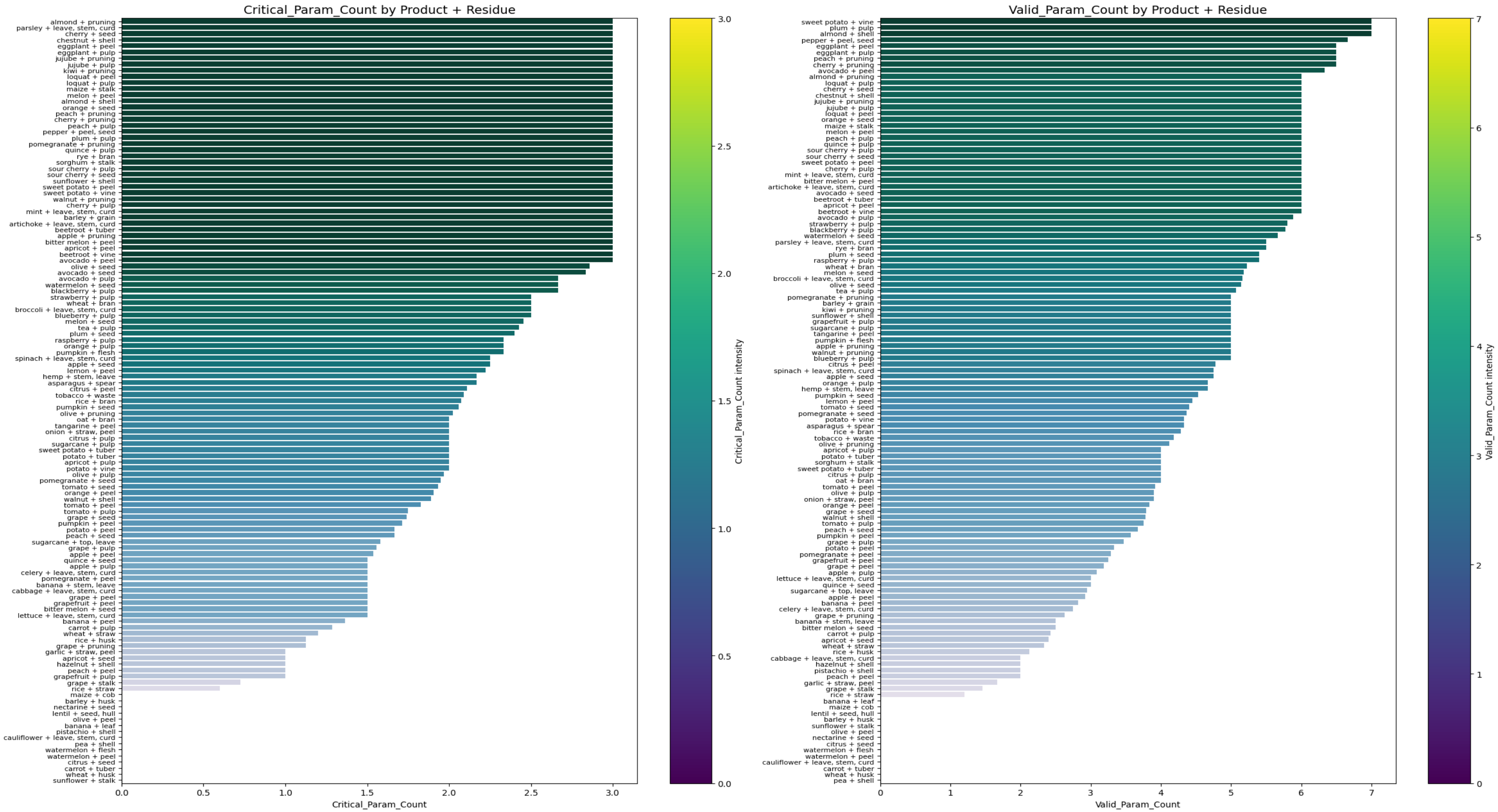

Figure 13. Detailed Parameter of SFE Score-Critical_Param_Count and Valid_Param_Count

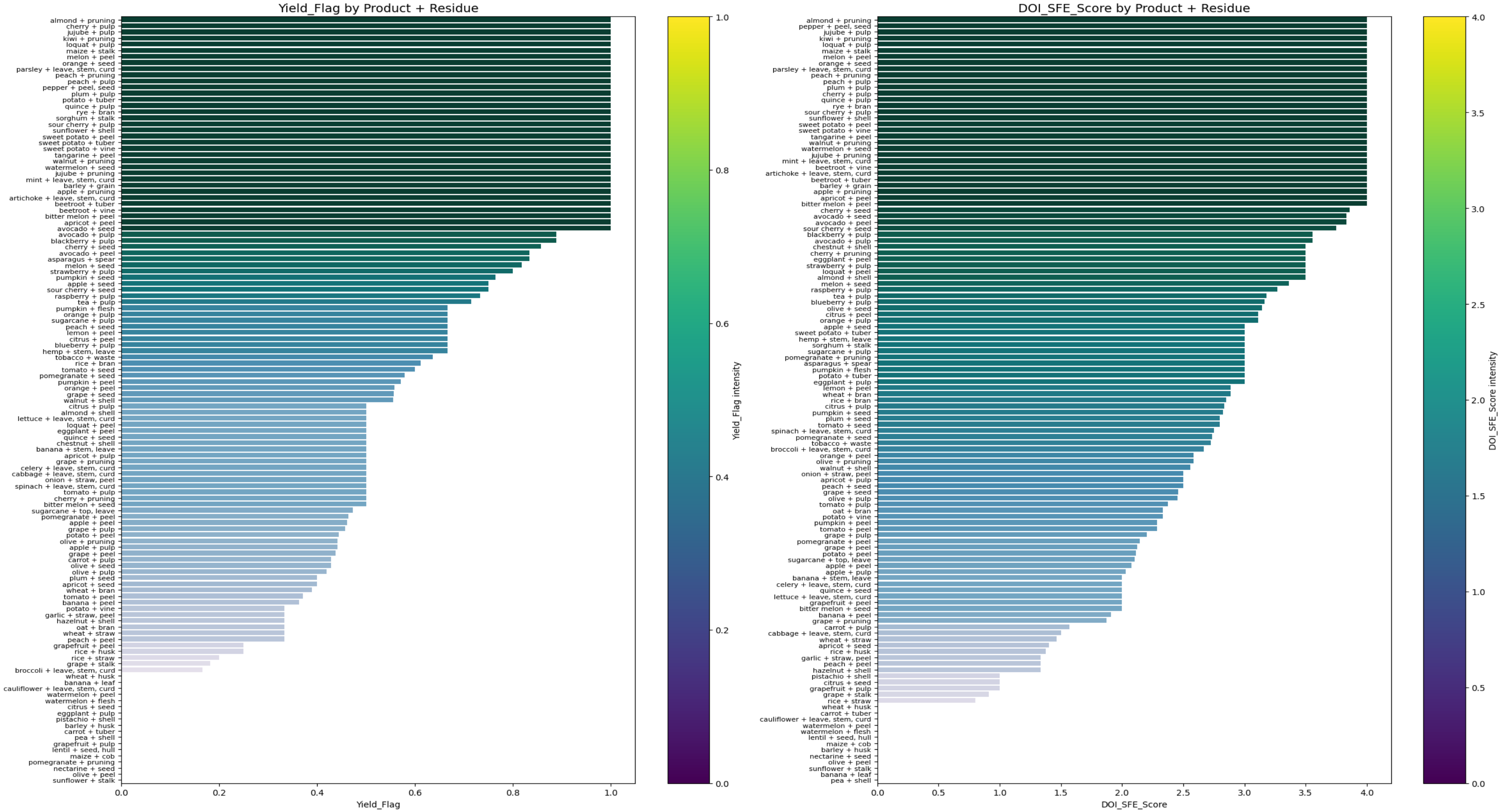

Figure 14. Detailed Parameter of SFE Score-Yield_Flag and DOI_SFE_Score

Figure 12-14 presents a series of bar graphs prepared to analyze, at the AR level, the individual parameters used in the construction of the SFE Score (see Table 5). Each figure visualizes a specific metric, enabling a comparative assessment of the depth and quality of scientific data reported for different product–residue pairs.

The SFE_Flag in Figure 12-left graph takes a value between 0 and 1, with a value of 1 indicating that all studies related to that product-residue pair were conducted using the SFE method. The fact that agro-industrial residues such as grape pulp and seeds, orange peel, and tea pulp rank high in this score indicates that the SFE method is particularly preferred for these types of residue.

The Parameter_Flag in Figure 12-right graph is a value between 0 and 2, reflecting the number of SFE parameters (such as temperature, pressure, time, S/F ratio, solvent type, and flow rate) included in each publication. The findings indicate that residues such as pomegranate seeds, tomato pulp, and olive pomace are prominent in this field, demonstrating that these studies offer rich content not only in terms of methodological but also experimental parameters.

Critical_Param_Count in Figure 13-left graph represents the average number of critical SFE parameters (temperature, pressure, and extraction time) reported in the literature for each product- residue pair. The findings indicate that the high ranking of residues such as orange peel and pomegranate peel on this list suggests that initial process conditions in future SFE studies for these raw materials can be determined more reliably based on the literature.

Valid_Param_Count in Figure 13-right graph shows the total number of valid parameters reported, taking into account other technical data (e.g., S/F ratio, solvent type, cosolvent use) in addition to the critical parameters. The findings indicate that a high number of different data sets were reported for some residues, such as olive pomace, tomato pomace, and orange peel.

Yield_Flag in Figure 14-left graph represents the average ratio of the yield of the product obtained in the extraction study to whether it is found in the literature.

Findings show that this information is frequently found in waste products such as orange peel, pomegranate peel, and olive seeds, but yield information is not available for some of these products.

The DOI_SFE_Score in Figure 14-right graph is calculated by averaging the weighted values of submetrics, including SFE usage, parameter quality, and yield information. This score reflects the quality of the literature in both qualitative and quantitative terms. The findings indicate that pomegranate peel, orange peel, tomato pulp, and olive pulp are among the top-ranked product-residue pairs, indicating that these products have been extensively studied in the literature.

While analyses based on SFE parameters and yield information technically reveal the level of study of ARs within the scope of SFE, they do not provide a direct insight into the bioactive compounds derived from these residues. In this context, various analyses were conducted to determine the Bioactive Score based on AR, considering the diversity of bioactive compounds reported in the literature, their functional effects, and sectoral applications.

The relationship between the Bioactive Score and publication density and content depth is shown in Figure 15. The horizontal axis of the graph displays the Bioactive Score (averaged values based on the product and residue). In contrast, the vertical axis displays the number of publications (DOI) in the literature about the product-residue pair in question. The size of the bubbles reflects the number of bioactive compound classes (e.g., phenolics, flavonoids, carotenoids, etc.) reported in the studies. The color scale corresponds to the Bioactive Score level of the relevant combination.

The findings indicate a partial but non-linear relationship between the number of publications and the Bioactive Score. ARs such as pomegranate pulp, rice bran, tomato pulp, and orange peel stand out with both a high number of publications and relatively high Bioactive Score values. Conversely, some ARs, despite a limited number of studies, have high Bioactive Score values. ARs such as blackberry pulp, strawberry pulp, and pumpkin peel, despite having few publications, are rich in bioactive compounds.

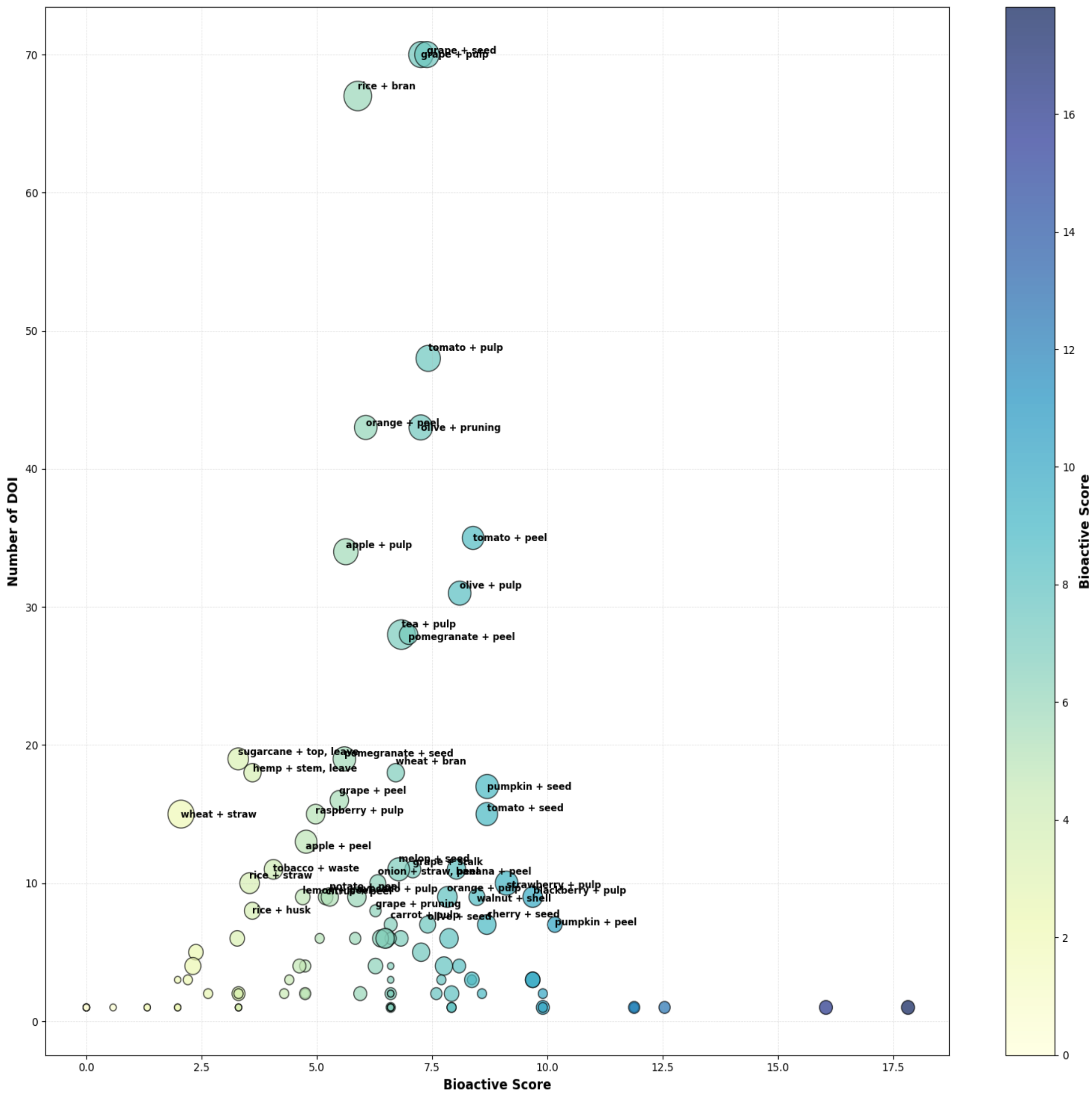

Figure 15. Bioactive Score vs Publication Instensity Bubble Chart

Of the parameters used in producing the Bioactive Score, separate analyses were conducted at the AR level only for the bioactive compound classifications and sectoral applications evaluated under Adjustment Factor 1 and Adjustment Factor 3 (see Table 6).

Because the presence of functional effects in Adjustment Factor 2 varied considerably in terms of content and was treated solely as descriptive data in this study, no additional graphical analysis was presented for this component. The diversity of information reported in the literature regarding bioactive compound classifications and sectoral applications at the level of AR is visualized in Figure 16 through binary heatmaps generated for each component.

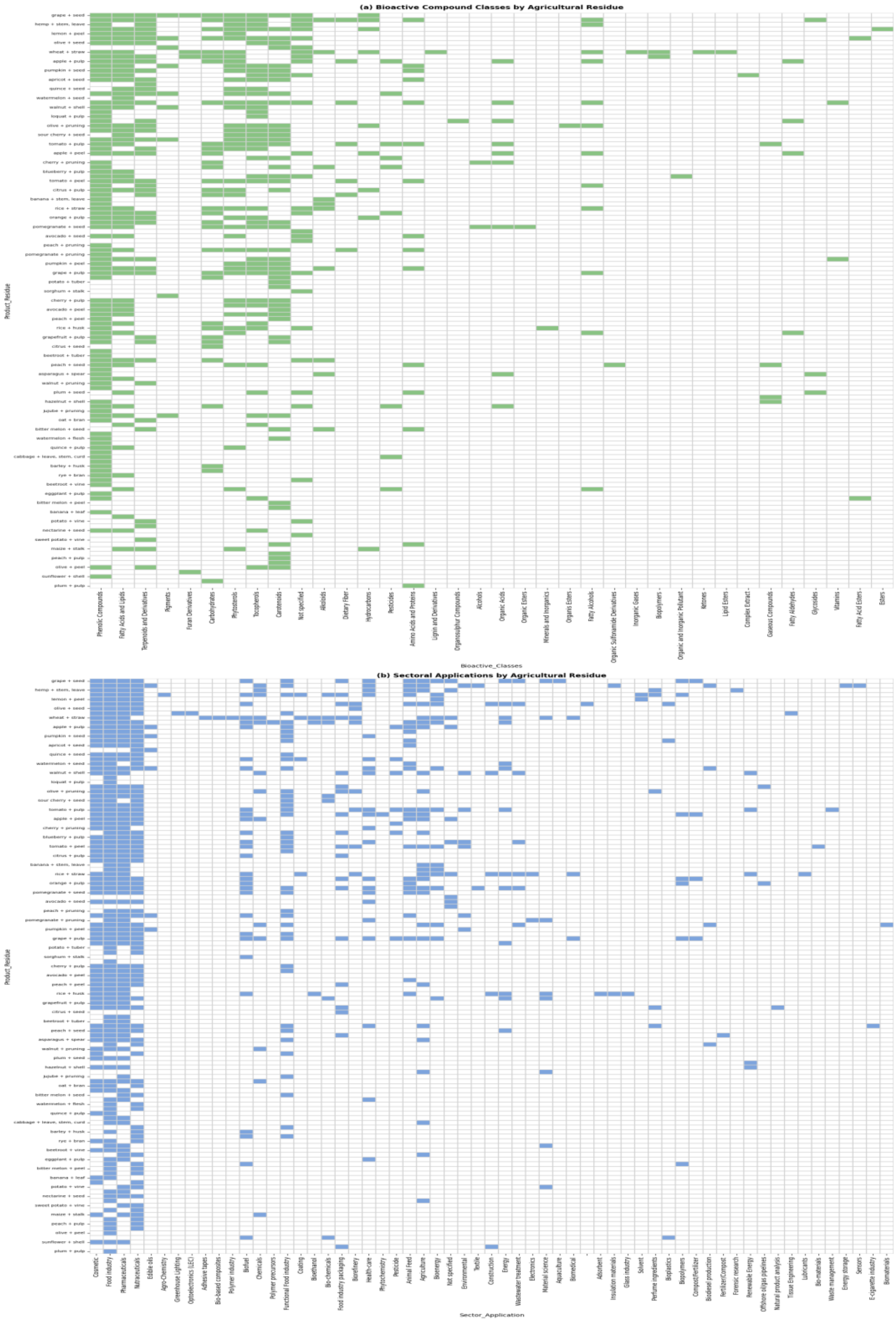

Figure 16. Distributions of Bioactive Compound Classes and Sectoral Applications

Figure 16 (a) presents the first heatmap, which shows which bioactive compound classes (e.g., phenolics, flavonoids, carotenoids, fatty acids) are reported in each product-waste combination. In the visual, the compound classes on the horizontal axis correspond to the product+waste pairs listed on the vertical axis. Areas highlighted in green on the map indicate that the relevant compound class is reported in at least one publication for that product+waste combination. A total of 42 different product+waste pairs report a bioactive compound in at least one publication. Wastes such as pomegranate peel, tomato pulp, orange peel, olive pulp, and grape seed, in particular, contain numerous bioactive compounds and are observed to be quite rich in content.

Figure 16 (b) presents the second heatmap, which displays sectoral application areas at the product and waste levels. In this analysis, sectors where the use of bioactive compounds is reported in the literature (e.g., food, cosmetics, pharmaceuticals, nutraceuticals, biofuels, and animal feeds) are analyzed separately. Purple shades indicate that each product+waste pair is associated with at least one publication related to that sector. It is particularly noteworthy that the pulps of products such as tomatoes, pomegranates, grapes, and oranges have wide applications in both the food, pharmaceutical, and cosmetic sectors. Furthermore, some items, such as olive pulp, walnut shells, and almond waste, appear to have the potential to be utilized in numerous sectors.

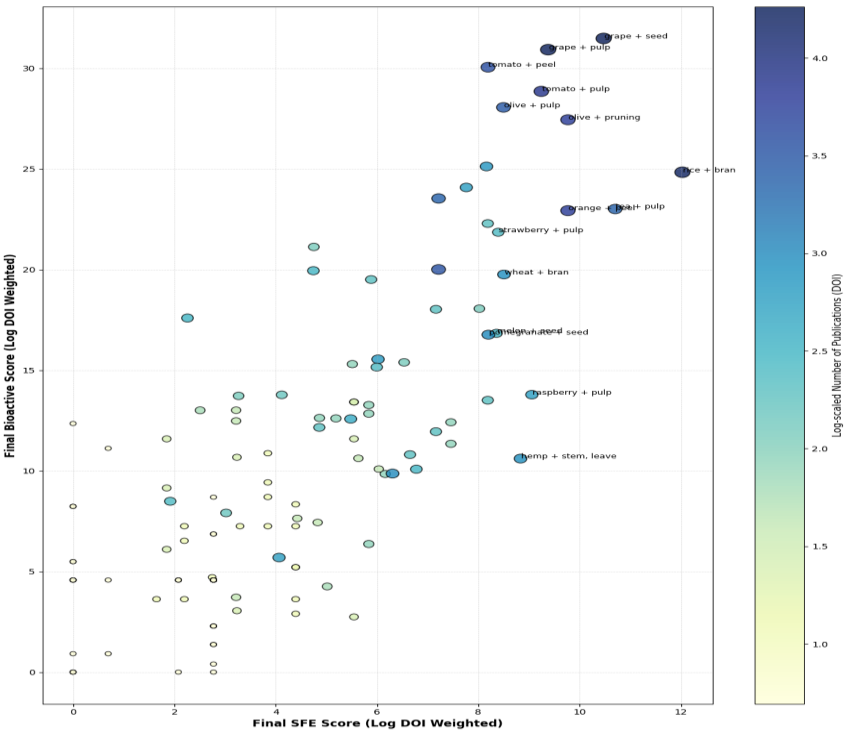

Figure 17. Final SFE and Final Bioactive Score Distributions

The analyses conducted so far have included article-based analyses of SFE and bioactive compound scores. Because these scores should be evaluated not only based on technical achievements or content richness, but also on their level of representation in the literature, the Final SFE Score and final Bioactive Score were calculated for each product-residue combination using the methodology outlined in Section 3.5. The final SFE and bioactive score distributions at the product-residue levels are presented in Figure 17.

The horizontal axis represents the SFE Score, and the vertical axis represents the Bioactive Score. The color and size of the bubbles represent the literature publication density (based on the log DOI value) for the respective product-residue pair. The graph facilitates the identification of residue streams that stand out in terms of both technical study (SFE parameters and yield) and biological depth (bioactive diversity and functional impact).

The findings in the graph indicate that products such as grape pomace (both pulp and seed), tomatoes (pulp and peel), olives (pulp and pruning), pomegranates, and oranges have both high SFE scores and high Bioactive scores. These pairs have also been extensively studied in the literature and are represented by large bubbles. This indicates that these residues are both efficient in terms of extraction and rich in functional content. On the other hand, some product-residue pairs stand out with high scores, particularly in one dimension (SFE or Bioactive), despite having a relatively low number of publications. This demonstrates that even a small number of high-quality studies can influence the scoring system.

The distributions in the graph indicate a statistically significant and strong positive relationship between the SFE Score and the Bioactive Score. According to the Pearson correlation analysis results, a statistically significant positive correlation of 77.6% was found between the two variables ($r = 0.776$, $p < 0.001$). This finding demonstrates that product-residue pairs, which have a rich literature on SFE parameters and yield information, also offer high content richness in bioactive compounds and functional effects. This supports the prioritization of combinations with strong representation from both technical and biological perspectives in product selection.

5.3. AHP-TOPSIS Results: Identification of Priority Agricultural Residues

The criteria weights in the AHP process were calculated using the methodology described in Section 3.5. The results are presented in Table 23. The Final SFE Scores and Final Bioactive Scores of ARs obtained as a result of the methodology outlined in Section 3.4 and the rankings obtained after the AHP-TOPSIS analysis mentioned in Section 3.5 are included in Appendix D.

According to Table 23, the Bioactive Score emerged as the most important criterion, accounting for a weight of 55.49%. This criterion was followed by the SFE Score with a weight of 25.16%, while the Mean Available Dry Residue Amount and CV Ratio criteria were equally less important with a weight of 9.67%. This distribution demonstrates that in a scenario focused on bioactive compound production, the importance given to content quality overrides production-based factors such as quantity and variability. The consistency of the AHP analysis was also found to be acceptable. The calculations yielded λ_{max} of 4.0435, a CI of 0.0145, and a CR of 0.0161. Since CR < 0.10, the comparison matrix was considered consistent.

Table 23. AHP Criteria Weights

Criteria	Mean Available Dry Residue	CV	SFE Score	Bioactive Score	Weight
Mean Available Dry Residue	1	1	1/3	1/5	0.0967
CV	1	1	1/3	1/5	0.0967
SFE Score	3	3	1	1/3	0.2516
Bioactive Score	5	5	3	1	0.5549

The results for the top 20 product-residue combinations in the AHP-TOPSIS analysis are presented in Table 24. For each combination, the table shows the mean available dry residue amount (in thousand of tons), the CV, the logarithmically weighted SFE Score and Bioactive Scores, the calculated TOPSIS score, and the ranking obtained based on this score.

An examination of the top 20 residues reveals that agro-industrial residues from products subjected to intensive processing by the food industry stand out. At the same time, some field residues also receive high scores. Grape seed and pulp stand out as the highest priority residues in the resulting ranking. These residues are followed by tomato pulp, tomato peel, and olive pulp, respectively.

Table 24. AHP-TOPSIS Results for Top 20 Agricultural Residue

Rank	Product	Residue Source	Residue	Mean Available Dry Residue (kton)	CV Ratio	SFE Score	Bioactive Score	TOPSIS Score
1	grape	Agro-Industry	seed	1.113	0.279	10.474	31.484	0.8548
2	grape	Agro-Industry	pulp	4.028	0.256	9.378	30.927	0.8395
3	tomato	Agro-Industry	pulp	64.562	0.356	9.243	28.855	0.8203
4	tomato	Agro-Industry	peel	35.141	0.329	8.191	30.054	0.8153
5	olive	Field	pruning	100.590	0.428	9.768	27.444	0.8071
6	olive	Agro-Industry	pulp	235.690	0.426	8.497	28.058	0.8036
7	rice	Agro-Industry	bran	58.775	0.697	12.029	24.836	0.7687
8	pumpkin	Agro-Industry	seed	0.070	0.289	8.161	25.124	0.7406
9	tea	Agro-Industry	pulp	91.164	0.201	10.703	23.008	0.7261
10	tomato	Agro-Industry	seed	35.009	0.275	7.763	24.081	0.7147
11	orange	Agro-Industry	peel	5.602	0.240	9.768	22.929	0.7135
12	pomegranate	Agro-Industry	peel	3.665	0.552	7.216	23.534	0.6922
13	blackberry	Agro-Industry	pulp	0.014	0.723	8.187	22.289	0.6764
14	strawberry	Agro-Industry	pulp	2.032	0.472	8.393	21.854	0.6716
15	wheat	Agro-Industry	bran	1883.486	0.122	8.506	19.757	0.6510
16	apple	Agro-Industry	pulp	5.283	0.211	7.215	20.006	0.6159
17	pumpkin	Agro-Industry	peel	0.169	0.380	4.753	21.127	0.6053
18	walnut	Agro-Industry	shell	45.285	0.402	5.884	19.505	0.5852
19	cherry	Agro-Industry	seed	2.968	0.451	8.021	18.058	0.5774
20	banana	Agro-Industry	peel	3.089	0.721	4.744	19.945	0.5756

This conclusion is supported by the fact that these products are frequently studied in the literature and contain high bioactive content. At the same time, the inclusion of relatively lesser-known but potentially influential residue sources, such as rice bran, pumpkin seeds, and tea pulp, in the top 10 demonstrates that the methodology successfully considers not only literature density but also structural factors, including production volume and stability.

For use in subsequent stages of this study, the focus area was narrowed by reducing the number of product-residue pairs. In this context, grape (pulp and seeds), tomato (pulp, peel, and seeds), and olive (pruning) waste were selected as priority ARs. Thus, the study continued with in-depth analyses of residue types from three different products.In addition to the bioactive compound production-based scenario results, a sensitivity analysis was conducted by testing alternative AHP comparison matrices to evaluate the robustness of the prioritization process.

In this context, three scenarios were designed to reflect different decision-making perspectives, and the results of the sensitivity analysis are summarized in Table 25.

- **Scenario A (Literature-oriented):** prioritizes literature-based indicators, assigning higher weights to the SFE Score and Bioactive Score.
- **Scenario B (Supply-oriented):** emphasizes supply-side factors, assigning greater importance to the available dry residue amount and CV ratio.
- **Scenario C (Balanced):** assumes equal weights for all four criteria, reflecting a neutral approach.

Table 25. Criteria Weights and Consistency Analysis According to AHP Scenarios

AHP Scenario	λ_{max}	CI	CR	Mean Available Dry Residue	CV Ratio	SFE Score	Bioactive Score
Bioactive Compound Production-Based Scenario (This Study)	4.0435	0.0145	0.0161	0.0955	0.0955	0.2495	0.5596
Scenario A (Literature-oriented)	4.0079	0.0026	0.0029	0.0790	0.0483	0.5423	0.3304
Scenario B (Supply-oriented)	4.1170	0.0390	0.0433	0.5650	0.2622	0.1175	0.0553
Scenario C (Balanced)	4.0000	0.0000	0.0000	0.2500	0.2500	0.2500	0.2500

All scenarios produced acceptable consistency ratios (CR < 0.10), indicating that the matrices are methodologically reliable. The differences between the scenarios highlight how variations in decision-making perspectives can shift the relative importance of criteria. For instance, Scenario A confirms the strong influence of literature-driven indicators, while Scenario B demonstrates how prioritizing supply-side parameters can significantly alter the ranking outcomes. The Balanced Scenario serves as a benchmark for assessing stability across various criteria.

Table 26 presents the results for the first 10 product-residue pairs across the four different AHP scenarios. The comparison reveals notable differences across decision-making perspectives. In the bioactive-based and literature-oriented scenarios, residues with strong bioactive potential and well-documented SFE studies—particularly grape (seed and pulp), tomato (pulp and peel), and olive residues—consistently appear among the top-ranked options. The balanced scenario confirms this pattern, suggesting that even when all criteria are treated equally, these residues retain high priority due to their combined advantages of production volume, bioactive potential, and methodological support. This consistency demonstrates the robustness of grapes, tomatoes, and olives as leading candidates for SFE-based valorisation. By contrast, the supply-oriented scenario produces a substantially different ranking. Here, the dominance of large-scale agricultural outputs, such as wheat, maize, and barley by-products, shifts the prioritization away from residues with substantial bioactive literature. This result underscores the decisive impact of supply-side parameters: when raw material availability and stability are given greater weight, residues with higher absolute tonnage but lower bioactive documentation move to the forefront.

Table 26. Comparison of Top 10 Ranked Product-Residue Pairs Across AHP Scenarios

Rank	Bioactive Compound Production-Based Scenario (This Study)	Scenario A (Literature-oriented)	Scenario B (Supply-oriented)	Scenario C (Balanced)
1	Grape – Seed (Agro)	Rice – Bran (Agro)	Wheat – Straw (Field)	Wheat – Bran (Agro)
2	Grape – Pulp (Agro)	Grape – Seed (Agro)	Wheat – Bran (Agro)	Grape – Seed (Agro)

Table 26. (continued)

3	Tomato – Pulp (Agro)	Tea – Pulp (Agro)	Maize – Cob (Agro)	Grape – Pulp (Agro)
4	Tomato – Peel (Agro)	Olive – Pruning (Field)	Wheat – Husk (Agro)	Tea – Pulp (Agro)
5	Olive – Pruning (Field)	Grape – Pulp (Agro)	Barley – Bran (Agro)	Olive – Pulp (Agro)
6	Olive – Pulp (Agro)	Tomato – Pulp (Agro)	Barley – Husk (Agro)	Tomato – Pulp (Agro)
7	Rice – Bran (Agro)	Orange – Peel (Agro)	Barley – Stalk (Field)	Olive – Pruning (Field)
8	Pumpkin – Seed (Agro)	Olive – Pulp (Agro)	Chickpea – Stem/Leaf (Field)	Tomato – Peel (Agro)
9	Tea – Pulp (Agro)	Tomato – Peel (Agro)	Sunflower – Stalk (Field)	Rice – Bran (Agro)
10	Tomato – Seed (Agro)	Pumpkin – Seed (Agro)	Barley – Straw (Field)	Orange – Peel (Agro)

Overall, the analysis highlights two key insights. First, grape, tomato, and olive residues emerge as universally robust candidates, maintaining high ranks under all but the supply-oriented perspective. Second, the supply-driven scenario illustrates that policy choices prioritizing agricultural volume over scientific feasibility can substantially alter strategic focus. These findings emphasise that residue prioritisation is not fixed but depends strongly on whether the decision-making framework emphasises literature-based feasibility, supply availability, or a balance of both.

5.4. Potential Bioactive Compound Production and Revenue Estimations

Analyses were conducted to determine the potential production of bioactive compounds from ARs prioritized through the AHP–TOPSIS framework. For each product–residue pair, the minimum, average, and maximum yields reported in the literature were collected. Two levels of yield assessment were considered:

- **Bulk extract yield**: the total crude extract obtained from the residue using the SFE process, without separating individual bioactive components. This represents the overall extract mass that could be generated per unit of dry residue.
- **Specific compound yield**: the amount of a particular target bioactive compound (e.g., lycopene, resveratrol, hydroxytyrosol) quantified within the

extract. This is reported in the literature as concentration values (e.g., mg/g extract or g/kg residue) and indicates the extract's functional or commercial potential.

These yield ranges were combined with the average recoverable dry residue quantities (assuming complete processing of the residue) to calculate potential production volumes under three scenarios—pessimistic, base, and optimistic. The results are summarized in Tables 27 and 28, where Table 27 presents calculations for bulk extracts and Table 28 for specific bioactive compounds.

The findings in Table 27 indicate that tomato and olive residues play an active role in high-potential extract production. Approximately 8,199 metric tons of extract can be produced from tomato pulp with an average yield of 12.70%, and 24,948 metric tons from olive pulp with an average yield of 10.59%. For both AR types, 31,441 ktons and 90,033 ktons of extract can be produced under the maximum yield scenario, respectively. The high residue volume provided by tomato peels and seeds, combined with the high yield scenario, yields an average of approximately 38,000 tons of extract. Furthermore, despite the low residue volume of grape pulp, the high yield scenario yields 1,583 ktons of extract. Despite the low yields, olive pruning residue yields a substantial amount of extract due to its high volume.

Specific extract production calculations (See Table 28) are based on the bioactive compound contents found in bulk extracts or directly from the dry residue. Content values were evaluated based on both dry matter and extract, considering the minimum, average, and maximum values reported in the literature. The findings in Table 28 indicate that tomato pulp is notable for its high lycopene content. Considering the average dry matter content of 19.57 g/kg, approximately 1263 tons of lycopene can be produced. Using extract-based content for the same waste, this amount averages around 25.89 tons. Similarly, tomato peels and seeds are important sources for lycopene production; for example, an average of 21.58 tons of lycopene can be obtained from tomato peels, and approximately 34.66 tons from tomato seeds.

Table 27. Potential Amount of Bulk Extract Production

Product	Residue	Mean Available Dry Residue (kton)	Yield Min (%)	Yield Mean (%)	Yield Max (%)	Bulk Extract Production Min (kton)	Bulk Extract Production Mean (kton)	Bulk Extract Production Max (kton)
Grape	Seed	1.11	0.09	12.35	22.03	0.00	0.14	0.25
Grape	Pulp	4.03	0.09	8.02	39.30	0.00	0.32	1.58
Tomato	Pulp	64.56	1.65	12.70	48.70	1.07	8.20	31.44
Tomato	Peel	35.14	2.50	11.50	79.00	0.88	4.04	27.76
Olive	Pulp	235.69	0.41	10.59	38.20	0.97	24.95	90.03
Olive	Pruning	100.59	0.03	6.85	36.00	0.03	6.89	36.21
Tomato	Seed	35.01	0.30	9.25	30.27	0.11	3.24	10.60

Table 28. Potential Amount of Specific Extract Production

Product	Residue	Compound Name/Basis	Mean Available Dry Residue (kton)	Bulk Extract Production Mean (kton)	Content Min (g/kg)	Content Mean (g/kg)	Content Max (g/kg)	Specific Extract Production Min (ton)	Specific Extract Production Mean (ton)	Specific Extract Production Max (ton)
Grape	Seed	Resveratrol/dry mass	1.11	0.14	0.00	0.06	0.11	0.00	0.06	0.12
Grape	Pulp	Resveratrol/dry mass	4.03	0.32	0.00	0.25	0.49	0.01	01.00	1.98
Tomato	Pulp	Lycopene/dry mass	64.56	8.20	0.03	19.57	39.10	1.94	1263.15	2524.36
Tomato	Pulp	Lycopene/extract	64.56	8.20	0.50	3.16	5.82	4.10	25.89	47.69
Tomato	Peel	Lycopene/dry mass	35.14	4.04	0.03	0.61	1.20	1.05	21.58	42.10
Olive	Pulp	Hydroxytyrosol/extract	235.69	24.95	0.70	3.19	5.68	17.46	79.58	141.70
Olive	Pulp	Oleuropein/dry mass	235.69	24.95	14.26	14.26	14.26	3360.93	3360.93	3360.93
Olive	Pulp	Oleuropein/extract	235.69	24.95	0.60	8.30	16.00	14.97	207.07	399.16
Olive	Pruning	Oleuropein/dry mass	100.59	6.89	0.04	7.15	14.26	4.02	719.22	1434.42
Olive	Pruning	Tocopherols/dry mass	100.59	6.89	2.00	2.00	2.00	201.18	201.18	201.18
Tomato	Seed	Lycopene/dry mass	35.01	3.24	0.92	0.99	1.06	32.21	34.66	37.11

Olive pulp and pruning residue are particularly noteworthy for their oleuropein and hydroxytyrosol content. While an average of 207.07 tons of oleuropein can be produced from olive pulp on an extract basis, this amount reaches a significantly higher level of 3,360.93 tons on a dry matter basis. Additionally, approximately 79.58 tons of oleuropein can be produced from olive pomace, which contains hydroxytyrosol, and 719.22 tons from olive pruning residue. 201.18 tons of tocopherol production are also anticipated from pruning residue.

Grape seeds and pomace have a lower potential for resveratrol production compared to other products. An average of 0.0565% resveratrol can be obtained from grape seeds, resulting in a total production of approximately 63 kg. For grape pomace, this amount can reach approximately 1,978 tons in the maximum scenario, with increasing residue volume.

The potential revenues that could be generated from the potential production scenarios in Tables 27 and 28 were calculated. The revenues from bulk extracts were calculated based on the maximum unit price for the minimum production scenario and the minimum unit price for the maximum production scenario. This approach was chosen to reflect the supply-demand relationship, assuming that increased production volumes would lower market prices. The results are shown in Table 29.

According to Table 29, the bulk extract production amount obtained from grape (seed) residue was calculated as approximately 0.001 kton in the minimum scenario, 0.137 kton in the average scenario, and 0.245 kton in the maximum scenario. In the literature, the unit price of this extract ranges from \$7.86 to \$80.00/kg. In this context, potential revenues range from a minimum of \$0.07 million to an average of \$4.77 million and a maximum of \$19.62 million. The average bulk extract production calculated for grape (pulp) residue is 0.323 ktons, varying between a minimum of 0.004 ktons and a maximum of 1.583 ktons. Considering market prices, the potential revenue range is \$0.39 million (minimum), \$22.02 million (average), and \$210.54 million (maximum). These values suggest that, despite the low volume of residue from grape pomace, a substantial amount of revenue can be generated from its processing.

Table 29. Potential Bulk Extract Revenues Based on Production and Price Scenarios

Product	Residue	Bulk Extract Production Min (kton)	Bulk Extract Production Mean (kton)	Bulk Extract Production Max (kton)	Price Min ($/kg)	Price Mean ($/kg)	Price Max ($/kg)	Revenue Min (Million USD)	Revenue Mean (Million USD)	Revenue Max (Million USD)
Grape	Seed	0.00	0.14	0.25	7.86	34.65	80.00	0.07	2.12	1.93
Grape	Pulp	0.00	0.32	1.58	11.80	68.15	133.00	0.39	12.24	18.68
Tomato	Pulp	1.07	8.20	31.44	35.40	47.20	59.00	45.93	315.37	1113.03
Tomato	Peel	0.88	4.04	27.76	59.00	59.00	59.00	51.83	238.43	1637.90
Olive	Pulp	0.97	24.95	90.03	2.55	169.33	613.60	237.11	1778.57	229.59
Olive	Pruning	0.03	6.89	36.21	88.50	221.25	354.00	8.30	898.95	3204.80
Tomato	Seed	0.11	3.24	10.60	35.40	106.20	177.00	11.11	173.28	375.14

Tomato (Pulp) is one of the items with the highest dry waste volume. With a minimum extract yield of 1,065 ktons, an average of 8,199 ktons, and a maximum of 31,441 ktons, this waste offers a relatively large production capacity. Based on price estimates ($35.40–$59.00/kg), potential revenue ranges from a minimum of $45.93 million to an average of $386.99 million and a maximum of $1,855.05 million. This makes tomato pomace a significant source of bioactive extracts. Estimations based on tomato (peel) waste indicate an average bulk extract yield of 4,041 ktons. This commodity, with a minimum production range of 0.879 ktons and a maximum of 27,761 ktons, offers a relatively precise revenue estimate due to its fixed price ($59.00/kg). Potential revenues reach a minimum of $51.83 million, an average of $238.43 million, and a maximum of $1,637.90 million. Analysis for Tomato (Seed) calculated that with an average extract production of 3,238 ktons and a price range of $35.40–177.00/kg, revenues of a minimum of $3.72 million, an average of $343.83 million, and a maximum of $1,877.71 million could be achieved.

For Olive (Pulp), the average production amount was determined as 24,948 ktons, a minimum of 0.966 ktons, and a maximum of 90,033 ktons. The price range for this extract is quite wide ($2.55–$613.60/kg), creating a significant uncertainty in revenue calculations. Despite this, very high potential revenues emerge, with a minimum of $2.37 million, an average of $4,221.41 million, and a maximum of $55,256.37 million. This item exhibits high revenue variance due to its extreme price ranges. Olive (Pruning) waste is notable for its non-industrial (field) origin. The average extract quantity is 6,890 ktons, with a price range of $88.50 to $354.00/kg. The potential revenue range ranges from $2.75 million to $12,823.34 million, with the average scenario offering a significant potential of $1,524.57 million.

As a result, calculations based on the priority product-residue pairs in Table 29 indicate that AR can be converted into bulk extracts with high economic potential using the SFE method. The average bulk extract production volumes from grape (seed and pulp), tomato (pulp, peel, and seed), and olive (pulp and pruning) residue reached a total of 47.77 ktons, depending on the scenario. This production capacity could generate a potential revenue of at least $148 million, an average of $3.42 billion, and a maximum of $7.30 billion, based on calculations using unit sales prices reported in the literature.

In revenue calculations based on specific extracts, a logarithmically decreasing price model was applied due to the wide range of content values and the high economic value of the target compounds. This scenario allows for a decrease in unit prices if market supply increases. The results are presented in Table 30.

For resveratrol derived from grape seeds, a revenue of approximately $0.012 million is expected, with approximately 0.002 tons of extract in the lowest production scenario. However, this amount increases to 0.124 tons at maximum production, resulting in a potential revenue of $0.109 million. For grape pulp, resveratrol production is expected to yield $1.75 million at production volumes of up to 1.978 tons per year. Due to the variability in dry mass and extract-based lycopene contents obtained from residues such as tomato pulp and peel, for example, a revenue of only $18.68 million is estimated for 1.583 ktons of tomato pulp production. However, this value can reach a minimum of $3.65 million at higher production levels.

Significantly higher revenue potential has been observed for hydroxytyrosol and oleuropein, which are obtained from olive pulp and pruning residue. In particular, the olive pulp scenario, which contains only 14.26% oleuropein on a dry weight basis, yields a fixed production of 3361 tons, generating approximately $118.98 million in fixed revenue. For other oleuropein and tocopherol sources, production amounts are more variable, with potential revenue estimates ranging from a minimum of $0.971 million to a maximum of $50.78 million.

When the results in Tables 29 and 30 are evaluated together, it is clear that both approaches offer different advantages and economic potential. The bulk extract scenarios demonstrate that processing all of the residue can achieve much higher production volumes, resulting in a correspondingly high revenue potential. For products that generate high amounts of residue, such as tomatoes and olives, the revenue that can be generated from bulk extracts reaches billions of dollars in the most extreme scenarios. For example, bulk extract from olive pulp residue alone offers a remarkable potential of $229.59 million, with a production of approximately 90.03 ktons in the maximum scenario. Similarly, revenues for items such as tomato peel and tomato seed, with production capacities of 27.76 ktons and 10.60 ktons, reached $1.64 billion and $375.14 million, respectively.

Table 30. Specific Extract Production and Potential Revenue Estimates under Log Prices

Product	Residue	Compound Name	Specific Extract Production Min (ton)	Specific Extract Production Mean (ton)	Specific Extract Production Max (ton)	Price at Qmin ($/kg)	Price at Qmean ($/kg)	Price at Qmax ($/kg)	Revenue Min (Million $)	Revenue Mean (Million $)	Revenue Max (Million $)
Grape	Seed	Resveratrol	0.00	0.06	0.12	5430.41	3092.80	885.00	0.01	0.20	0.11
Grape	Pulp	Resveratrol	0.01	0.99	1.97	5467.85	2586.08	885.00	0.07	2.57	1.75
Tomato	Pulp	Lycopene (dry)	1.94	1263.15	2524.36	1883.82	199.57	7.40	3.65	252.09	18.68
Tomato	Pulp	Lycopene (extract)	4.10	25.89	47.69	1270.76	339.74	7.40	5.21	8.80	0.35
Tomato	Peel	Lycopene	1.05	21.58	42.10	1766.84	381.18	7.40	1.86	8.22	0.31
Olive	Pulp	Hydroxytyrosol	17.46	79.58	141.70	1430.43	1079.93	944.00	24.98	85.94	133.77
Olive	Pulp	Oleuropein (dry)	3360.93	3360.93	3360.93	35.40	35.40	35.40	118.98	118.98	118.98
Olive	Pulp	Oleuropein (extract)	14.97	207.07	399.16	177.65	64.28	35.40	2.66	13.31	14.13
Olive	Pruning	Oleuropein (dry)	4.02	719.22	1434.42	241.24	60.50	35.40	0.97	43.52	50.78
Olive	Pruning	Tocopherols	201.18	201.18	201.18	10.00	10.00	10.00	2.01	2.01	2.01
Tomato	Seed	Lycopene	32.21	34.66	37.11	89.67	47.12	7.40	2.89	1.63	0.27

On the other hand, while produced in smaller quantities, specific extracts offer significant revenue potential thanks to the high unit prices of the target compounds. However, because the content ratios and prices for these extracts are highly variable, a wider range of uncertainty is observed. Under the logarithmically decreasing price assumption, revenue from specific extracts is concentrated at USD 133.77 million (Hydroxytyrosol - olive pulp), USD 118.98 million (Oleuropein - olive pulp, fixed price), and USD 50.78 million (Oleuropein - olive pruning) in the maximum scenarios. In other words, even the highest revenues are more limited compared to bulk extracts. However, specific extracts have the potential to generate high added value by being sold in much smaller quantities at much higher prices.

The economic analysis model developed for the SFE process was examined at three different scales to assess AR processing capacity under more realistic production scenarios: 1,000 tons/year (laboratory–small pilot scale), 10,000 tons/year (pilot–semi-industrial scale), and 30,000 tons/year (full industrial scale).

A quota allocation approach was applied to realistically distribute the annual processing capacity (1,000, 10,000, and 30,000 tons/year) determined for each scale scenario among the various types of AR. This approach first determined the waste generation times (e.g., post-harvest harvestable months) for each product, determining their distribution throughout the year. Monthly processing capacity was then defined based on this distribution. Each month's capacity was then shared equally or proportionally among the product- residue pairs available for collection in that month, based on their production volume. However, in some cases, the monthly quota allocated for a particular product- residue pair exceeded the total potential waste amount of that product. In these cases, quota transfers were made to other wastes within the relevant product group (e.g., a triple separation of pulp, peel, and seed for tomatoes) to avoid excess residue. This method maintained total processing capacity within the same product family while ensuring an appropriate distribution of residue quantities. This method systematically ensured the full utilization of processing plant capacity and implemented a realistic resource management model based on a waste generation schedule.

Table 31. Scenario-Based Potential Production and Revenue from Bulk and Specific Extracts

Product	Residue	Extract	Available Dry Residue (kton/year)	Scenario (ton/year)	Months	Quota (ton/year)	Yield (%)	Composition (g/kg dry mass)	Production (ton/year)	Literature Price ($/kg)	Scenario Price ($/kg)	Revenue (1,000 $ /year)
grape	**seed**	**Bulk extract**	1.11	1000.00	3	136.36	0.09	-	0.12	7.86	78.48	0.96
grape	**pulp**	**Bulk extract**	4.03	1000.00	3	136.36	0.09	-	0.12	11.80	131.23	1.45
tomato	**pulp**	**Bulk extract**	64.56	1000.00	4	181.82	1.65	-	3.00	35.40	54.85	106.20
tomato	**peel**	**Bulk extract**	35.14	1000.00	4	181.82	2.50	-	4.55	59.00	59.00	268.18
olive	**pulp**	**Bulk extract**	235.69	1000.00	2	90.91	0.41	-	0.37	2.55	585.75	0.95
olive	**pruning**	**Bulk extract**	100.59	1000.00	2	90.91	0.03	-	0.03	88.50	352.93	2.49
tomato	**seed**	**Bulk extract**	35.01	1000.00	4	181.82	0.30	-	0.55	35.40	168.68	19.31
grape	**seed**	**Resveratrol**	1.11	1000.00	3	125.00	-	0.0020	0.00	885.00	885.00	0.22
grape	**pulp**	**Resveratrol**	4.03	1000.00	3	125.00	-	0.0030	0.00	885.00	885.00	0.33
tomato	**pulp**	**Lycopene**	64.56	1000.00	4	166.67	-	0.0300	0.01	7.40	7.40	0.04
tomato	**peel**	**Lycopene**	35.14	1000.00	4	166.67	-	0.0300	0.01	7.40	7.40	0.04
olive	**pulp**	**Oleuropein**	235.69	1000.00	2	83.33	-	14.2600	1.19	35.40	112.21	133.35
olive	**pruning**	**Oleuropein**	100.59	1000.00	2	83.33	-	0.0400	0.00	35.40	35.40	0.12
olive	**pruning**	**Tocopherols**	100.59	1000.00	2	83.33	-	2.0000	0.17	10.00	10.00	1.67
tomato	**seed**	**Lycopene**	35.01	1000.00	4	166.67	-	0.9200	0.15	7.40	7.40	1.13

Table 31 (Continued)

Product	Residue	Extract	Available Dry Residue (kton/year)	Scenario (ton/year)	Months	Quota (ton/year)	Yield (%)	Composition (g/kg dry mass)	Production (ton/year)	Literature Price ($/kg)	Scenario Price ($/kg)	Revenue (1,000 $ /year)
grape	**seed**	**Bulk extract**	1.11	10000.00	3	1113.28	12.35	-	137.49	34.65	15.40	2117.44
grape	**pulp**	**Bulk extract**	4.03	10000.00	3	1613.99	8.02	-	129.44	68.15	58.55	7579.15
tomato	**pulp**	**Bulk extract**	64.56	10000.00	4	1818.18	12.70	-	230.91	47.20	42.70	9859.62
tomato	**peel**	**Bulk extract**	35.14	10000.00	4	1818.18	11.50	-	209.09	59.00	59.00	12336.36
olive	**pulp**	**Bulk extract**	235.69	10000.00	2	909.09	10.59	-	96.23	169.33	211.16	20319.67
olive	**pruning**	**Bulk extract**	100.59	10000.00	2	909.09	6.85	-	62.27	221.25	194.19	12092.83
tomato	**seed**	**Bulk extract**	35.01	10000.00	4	1818.18	9.25	-	168.18	106.20	78.95	13277.61
grape	**seed**	**Resveratrol**	1.11	10000.00	3	1113.28	-	0.0565	0.06	3201.93	885.00	55.67
grape	**pulp**	**Resveratrol**	4.03	10000.00	3	1386.72	-	0.2470	0.34	3201.93	885.00	303.13
tomato	**pulp**	**Lycopene**	64.56	10000.00	4	1666.67	-	19.5650	32.61	783.10	734.94	23965.01
tomato	**peel**	**Lycopene**	35.14	10000.00	4	1666.67	-	0.6140	1.02	1638.60	1394.49	1427.03
olive	**pulp**	**Oleuropein**	235.69	10000.00	2	833.33	-	14.2600	11.88	130.85	112.21	1333.46
olive	**pruning**	**Oleuropein**	100.59	10000.00	2	833.33	-	7.1500	5.96	130.85	157.47	938.26
olive	**pruning**	**Tocopherols**	100.59	10000.00	2	833.33	-	2.0000	1.67	22.50	21.31	35.52
tomato	**seed**	**Lycopene**	35.01	10000.00	4	1666.67	-	0.9900	1.65	776.82	1031.03	1701.20

Table 31 (Continued)

Product	Residue	Extract	Available Dry Residue (kton/year)	Scenario (ton/year)	Months	Quota (ton/year)	Yield (%)	Composition (g/kg dry mass)	Production (ton/year)	Literature Price ($/kg)	Scenario Price ($/kg)	Revenue (1,000 $ /year)
grape	**seed**	**Bulk extract**	1.11	30000.00	3	1113.28	22.03		245.26	80.00	7.86	19248.49
grape	**pulp**	**Bulk extract**	4.03	30000.00	3	7068.54	39.30		2777.94	133.00	11.80	364550.44
tomato	**pulp**	**Bulk extract**	64.56	30000.00	4	5454.55	48.70		2656.36	59.00	35.40	145703.76
tomato	**peel**	**Bulk extract**	35.14	30000.00	4	5454.55	79.00		4309.09	59.00	59.00	254236.36
olive	**pulp**	**Bulk extract**	235.69	30000.00	2	2727.27	38.20		1041.82	613.60	2.55	610240.25
olive	**pruning**	**Bulk extract**	100.59	30000.00	2	2727.27	36.00		981.82	354.00	88.50	346512.23
tomato	**seed**	**Bulk extract**	35.01	30000.00	4	5454.55	30.27		1651.09	177.00	35.40	278507.90
grape	**seed**	**Resveratrol**	1.11	30000.00	3	1113.28		0.1110	0.12	5518.86	885.00	109.36
grape	**pulp**	**Resveratrol**	4.03	30000.00	3	6386.72		0.4910	3.14	5518.86	4557.46	14291.65
tomato	**pulp**	**Lycopene**	64.56	30000.00	4	5000.00		39.1000	195.50	2183.00	734.94	143679.79
tomato	**peel**	**Lycopene**	35.14	30000.00	4	5000.00		1.1980	5.99	2183.00	1394.49	8352.98
olive	**pulp**	**Oleuropein**	235.69	30000.00	2	2500.00		14.2600	35.65	300.00	112.21	4000.3820
olive	**pruning**	**Oleuropein**	100.59	30000.00	2	2500.00		14.2600	35.65	300.00	157.47	5613.82
olive	**pruning**	**Tocopherols**	100.59	30000.00	2	2500.00		2.0000	5.00	35.00	21.31	106.57
tomato	**seed**	**Lycopene**	35.01	30000.00	4	5000.00		1.0600	5.30	2183.00	1031.03	5464.48

Both bulk and specific extract production were calculated based on the processing quantities allocated to each product group. Unit prices corresponding to these production quantities were estimated using a logarithmic declining price model, similar to the one used in the previous step. Potential revenue calculations were generated by multiplying the extract quantities obtained from the scenarios by these logarithmic prices. Thus, the economic outcomes that could be generated by SFE investments at different scales were evaluated in detail by product and extract type. The calculations for all these scenarios are presented in Table 31.

The findings in Table 31 show that economic outcomes vary significantly across different capacity scenarios. In the 1,000 tons/year scenario, despite the low production volume, specific components (such as resveratrol and oleuropein), which are particularly expensive in the literature, generate high unit revenue. However, total revenue is limited at this scale.

In the 10,000 tons/year scenario, significant production was achieved from both bulk extracts and specific components, with the highest returns being achieved, particularly through the utilization of tomato and olive residue. For example, tomato pulp extract generated approximately 9,860 thousand USD/year in revenue with a production of 231 tons/year, while olive pulp extract generated 20,320 thousand USD/year in revenue with a production of 96 tons/year. Among the specific components, significant revenue was generated from lycopene, oleuropein, and resveratrol. Although these components produced less than 1 ton in this scenario, their contribution to total revenue was significant due to their high unit prices.

In the 30,000 tons/year scenario, as the scale increased, processing capacity for some products exceeded the amount of waste, and production capacity limits were reached. At this scale, vast and standard wastes, such as tomato, olive, and grape waste, were utilized in high tonnage. For example, 4,309 tons/year of extract was produced from tomato peel, generating 254,236 thousand USD/year in revenue. One of the highest revenue items was olive pulp extract, which generated 610,240 thousand USD/year in revenue with a production of 1,042 tons/year and a scenario price of 613.60 USD/kg. High-priced specific ingredients such as lycopene also generated revenue exceeding 143,680 thousand USD/year with a production of 196 tons/year. In general, production growth became more advantageous under the logarithmic price structure as the scale increased, with the revenue contribution of many product–residue combinations increasing exponentially.

5.5. Macroeconomic Impacts: Input-Output Analysis

As part of the macroeconomic impact analysis, potential revenue estimates for three different production scenarios presented in Section 5.4 were integrated into the I-O model as a final demand shock. Thus, the direct and indirect impacts of SFE and extract production on total production volume, value added, and employment were numerically calculated.

Figure 16, presented in Section 5.2 to illustrate the sectors where bioactive ingredients are intensively used, highlights the key role of the food, cosmetics, and pharmaceutical sectors in this area. Therefore, the macroeconomic analysis was conducted exclusively for these three sectors, and the impacts were calculated using sector-based multipliers.

In this context, the production, value added, and employment multipliers for each sector were determined using the method described in Section 3.7 and are presented in Table 32. The employment multipliers here represent the number of physical workers, not monetary values.

Complementing the results calculated with the I-O model, a sectoral distribution simulation was performed by distributing the total potential revenue generated by the SFE across three main sectors (food, cosmetics, and pharmaceuticals) at different rates. This simulation involved five different extracts, three production scenarios (low, medium, and high), and 66 different sectoral utilization rate combinations (where the food, cosmetics, and pharmaceuticals sectors' shares are rounded up to 1), creating a dataset containing 990 observations. A sample of this dataset is presented in Appendix E to illustrate the structure of the sectoral distribution and impact calculations.

Table 32. Output, Value Added, and Employment Multipliers

Sector	Output Multiplier	Value Added Multiplier	Employment Multiplier*
Food	1.9430	0.7718	0.0050
Cosmetics	1.5561	0.5043	0.0030
Pharma	1.6026	0.6545	0.0072

**It was calculated on an employee/TL basis based on 2022 TUIK labour force statistics and 2022 I-O table, and then, since the applied demand shocks were USD-based, an employee/USD conversion was made based on the 2022 average exchange rate to ensure accuracy.*

In each combination, the total potential revenue generated from the relevant production scenario was distributed across sectors. The economic impacts were then calculated by applying the sector-based output, value added, and employment multipliers presented in Table 32. Figure 18 summarizes the results of this simulation.

The graphs in Figure 18 are arranged in rows by impact type (Production, Value Added, Employment) and in columns by production scenario (Low, Medium, and High). Each subgraph displays the linear impact magnitude as the sector share increases. The area fills on the graph represent the min-max range of impact values occurring in the same sector share for all extracts and reveal the potential difference between products.

In the first row where the production effect is examined with different sector shares, at the low scenario level (left column), the impact values are pretty limited, rarely exceeding $0.5 million. This demonstrates that even with different sector trends at low production volumes, the economic contribution is limited. In the medium scenario (mid column), the impacts reach tens of millions of dollars, while the production impact increases significantly when the food sector is given a higher share. In the high scenario (right column), the production impacts can exceed $2000 million; here, the food sector stands out as the sector with the steepest and highest level. The widening of the shading areas reveals significant variation among products, particularly in the high scenario, meaning that some products are much more sensitive to sectoral distribution.

The graphs in the second row show the value-added effects. The value-added effects are lower than the production effects due to the multiplier values, but a parallel increasing trend is observed. In particular, as the food sector share increases, the value-added contribution also increases. While the cosmetics and pharmaceutical sectors exhibit a relatively flat trend, variation increases significantly in the medium and high scenarios. This demonstrates that the value-added impact of some extracts is strongly influenced by sectoral distribution.

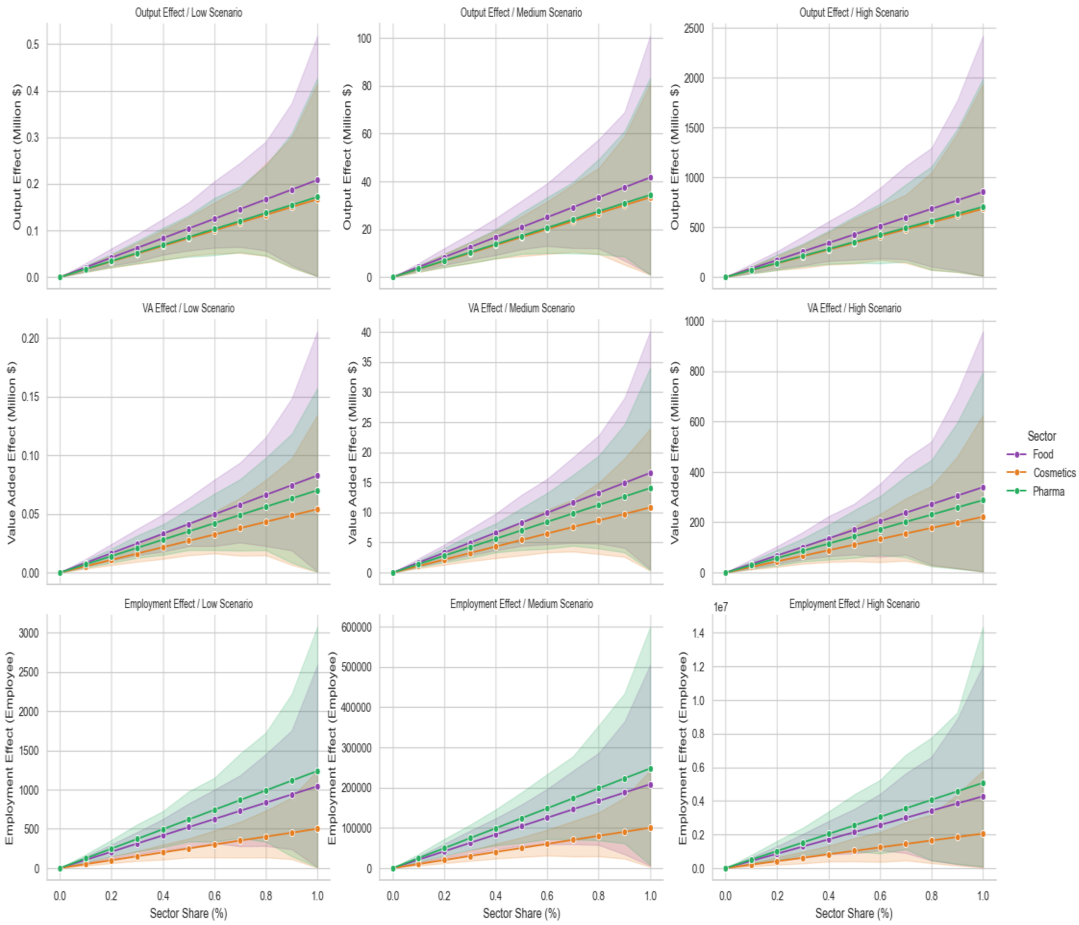

Figure 18. Effect of Sectoral Share by Scenario and Metric

The graphs in the third row show the employment impacts. While the impacts are in the thousands in the low scenario, this number rises to tens of thousands, or even millions, in the medium and high scenarios. The pharmaceutical sector, in particular, exhibits high variation in employment, even surpassing the food sector in some scenarios. This suggests that the employment contribution could be higher, especially for labour-intensive products or products where processing steps are used in the pharmaceutical channel. The shading is quite broad here, clearly demonstrating that employment is highly sensitive to sectoral distribution and varies by product.

The findings in Figure 18 show that the food sector generally stands out as the sector providing the highest economic contribution. In contrast, the pharmaceutical sector demonstrates a particularly high potential for employment. The cosmetics sector lags in all three metrics, indicating that the products and process structures in question have a more limited economic impact in this sector.

How each extract type responds to sectoral distribution: In order to evaluate which sectors yield more advantageous results in terms of production, value-added, and employment impacts, the analyses were deepened, and the results were visualized with graphs (Figures 19-23). In the graphs, the horizontal axis represents the food sector share, which is taken as the primary determinant of the distribution among the three sectors. In contrast, the vertical axis shows the output effect, value-added effect, and employment effect, respectively. The values at each point reflect the effects corresponding to the food, cosmetics, and pharmaceutical sectors and are separated by colors. The main reason for analyzing the food sector axis is that extracts have a high potential for use mainly in this sector. At the same time, it is observed that the bioactive compound production targets included in the TÜBİTAK-TAGEM Report (2022) aim to expand studies covering functional foods.

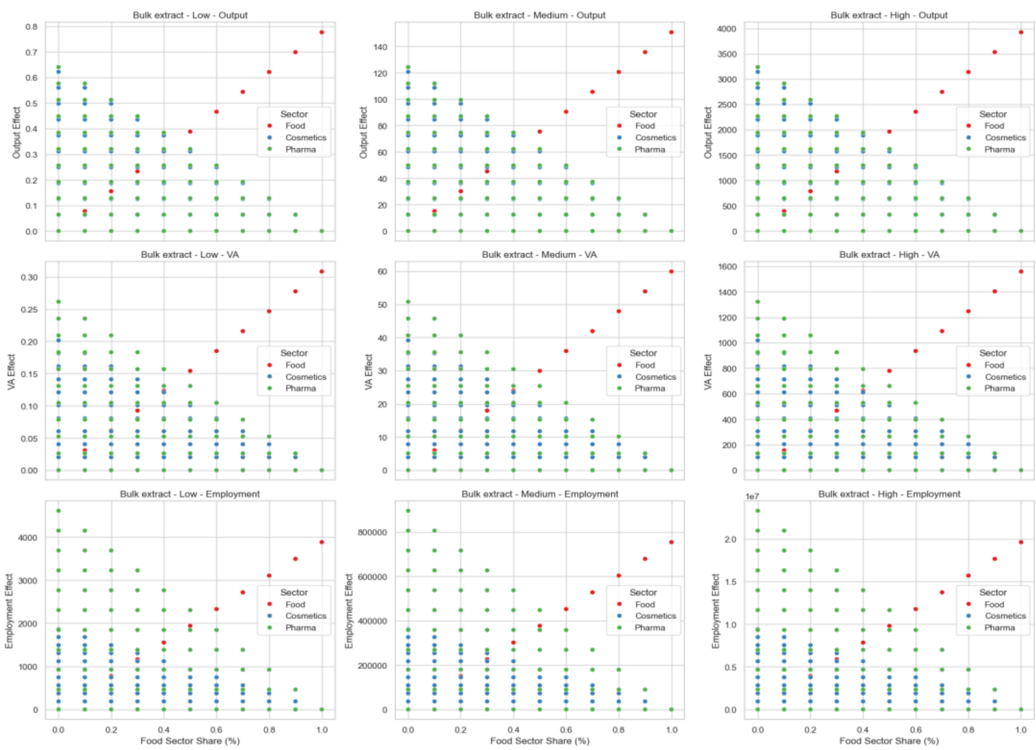

Figure 19. Effect of Sectoral Share by Scenario and Metric – Bulk Extract

Figure 19 shows the economic impacts of sectoral distribution for bulk extract under different production scenarios. The findings in the graph show that in the low scenario, the production and value-added effects are pretty limited, while the employment effect is relatively more pronounced. In the medium scenario, the effects become more visible across all metrics, and it is observed that the economic contribution increases as the share of the food sector increases. The high scenario, on the other hand, produces significant increases in economic output; this is particularly evident in the production and employment effects. Interestingly, the pharmaceutical sector surpasses the food sector in some distributional ratios in employment impact. This suggests that labor-intensive processes are becoming more dominant in the pharmaceutical sector.

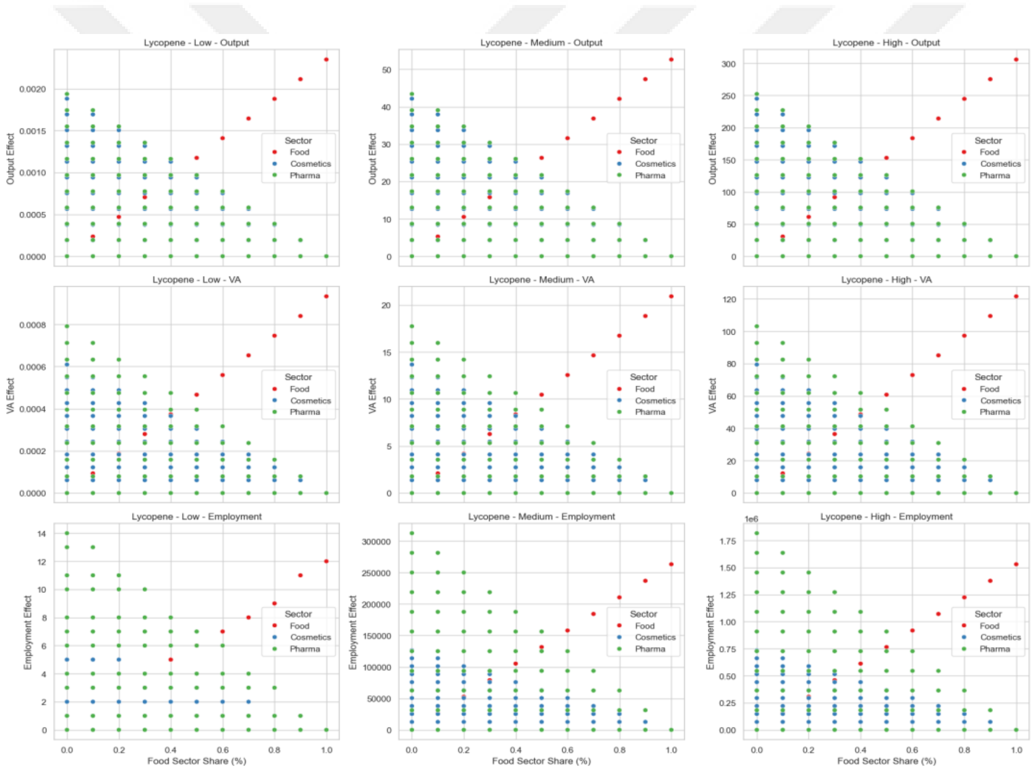

Figure 20. Effect of Sectoral Share by Scenario and Metric – Lycopene

Figure 20 shows the economic impacts of sectoral distribution for lycopene under different production scenarios. In the low scenario, the effects are relatively limited across all metrics. In particular, the production and value-added effects are negligible. On the other hand, in the high scenario, the production and value-added contributions reach significant levels, with the food sector being particularly prominent. In terms of employment impact, the pharmaceutical sector can surpass the food sector in some distribution ratios. While the food sector generally provides the highest output for lycopene, sensitivity to sector distribution is moderate. This demonstrates that lycopene's economic impacts are largely dependent on production volume and sectoral distribution.

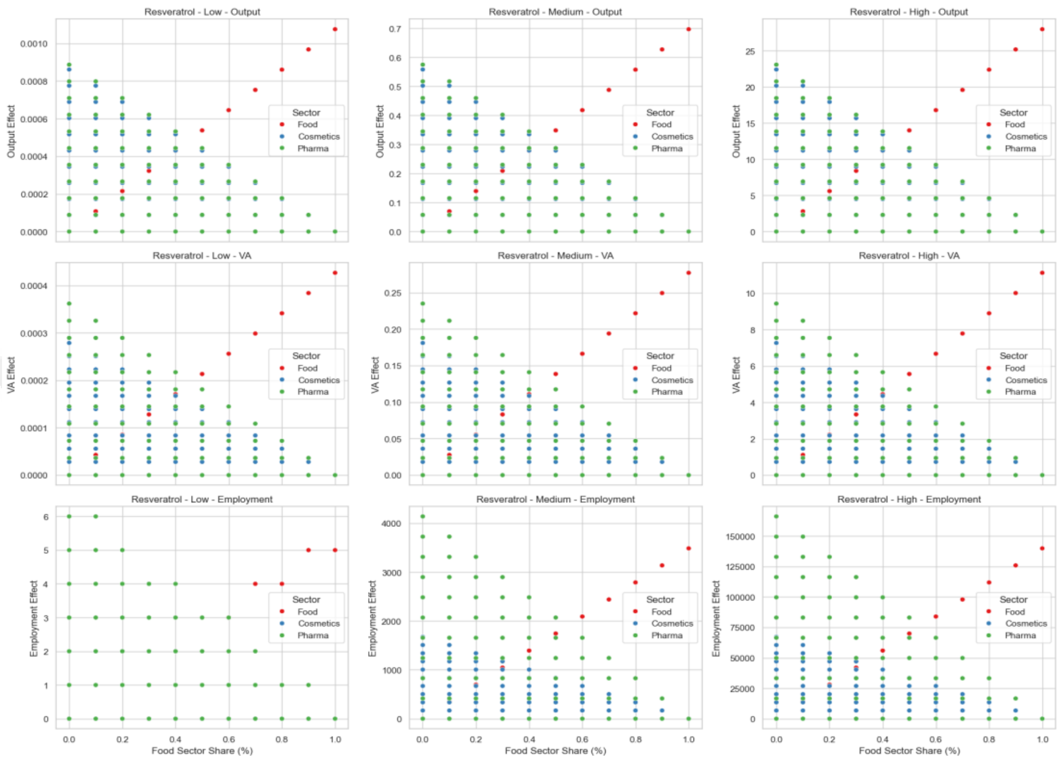

Figure 21. Effect of Sectoral Share by Scenario and Metric – Resveratrol

Figure 21 shows the economic impacts of resveratrol's sectoral distribution under different production scenarios. In the low and medium scenarios, the production, value-added, and employment impacts are negligible. In the high scenario, the effects become more pronounced, but this increase is more modest compared to bulk extract and lycopene. As the food sector's share increases, a slight increase in production and value-added impacts is observed. However, the pharmaceutical sector becomes more prominent in employment impact, surpassing food in some scenarios. Generally, resveratrol has a low to medium potential in terms of economic impacts, and it could contribute more significantly to the food sector, mainly if high production volumes are achieved.

Figure 22 shows the economic impacts of tocopherols under different production scenarios, with the sectoral distribution. While the impacts are pretty limited in the low scenario, the medium and high scenarios increase production, value added, and employment, particularly with a focus on the food sector. In all three scenarios, the food sector stands out as the sector with the highest impact across all metrics. The cosmetics and pharmaceutical sectors, on the other hand, provide lower contributions. While the pharmaceutical sector occasionally stands out in employment, it lags in terms of overall impact. These results suggest that tocopherols have the potential to create a more substantial economic impact, particularly in the food sector, with high-volume production.

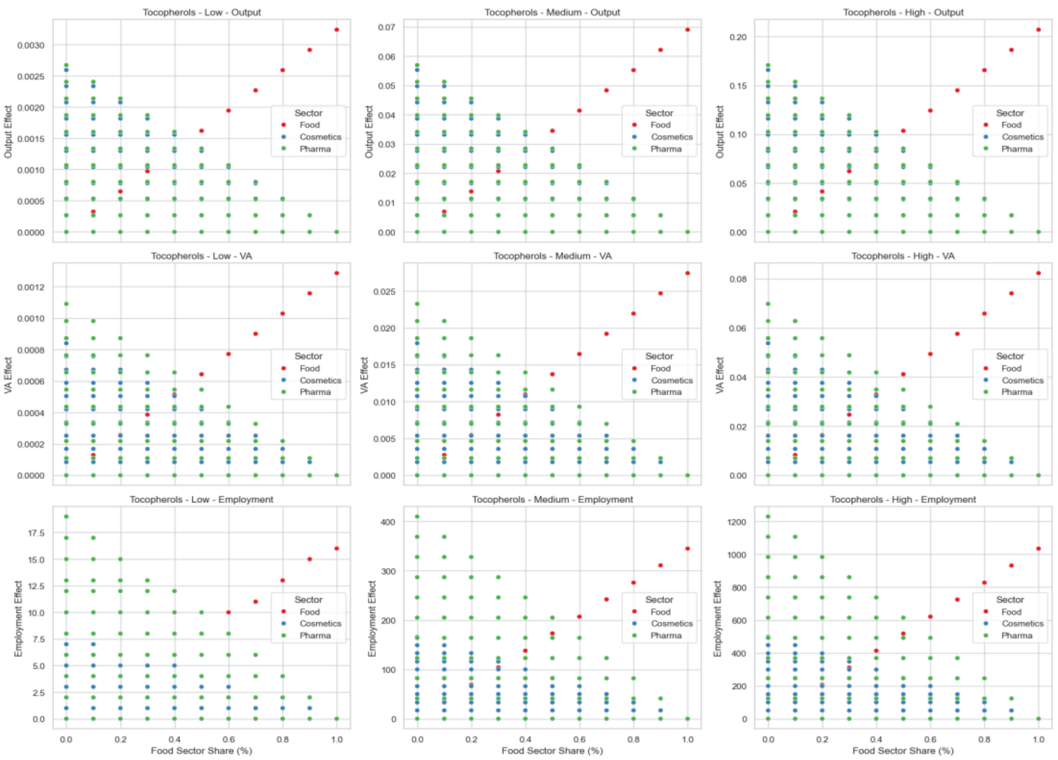

Figure 22. Effect of Sectoral Share by Scenario and Metric – Tocopherols

Figure 23 illustrates the economic impacts of oleuropein's sectoral distribution under different production scenarios. In the low and medium scenarios, the cosmetics sector produces strong results in terms of both production and value added, with values similar to those of the food sector. Regarding employment impact, the pharmaceutical sector is notable in all scenarios. While the food sector regains prominence in the high scenario, the impacts of other sectors are significantly increased. This demonstrates that oleuropein extract can offer a balanced economic contribution across different sectors thanks to its versatile potential.

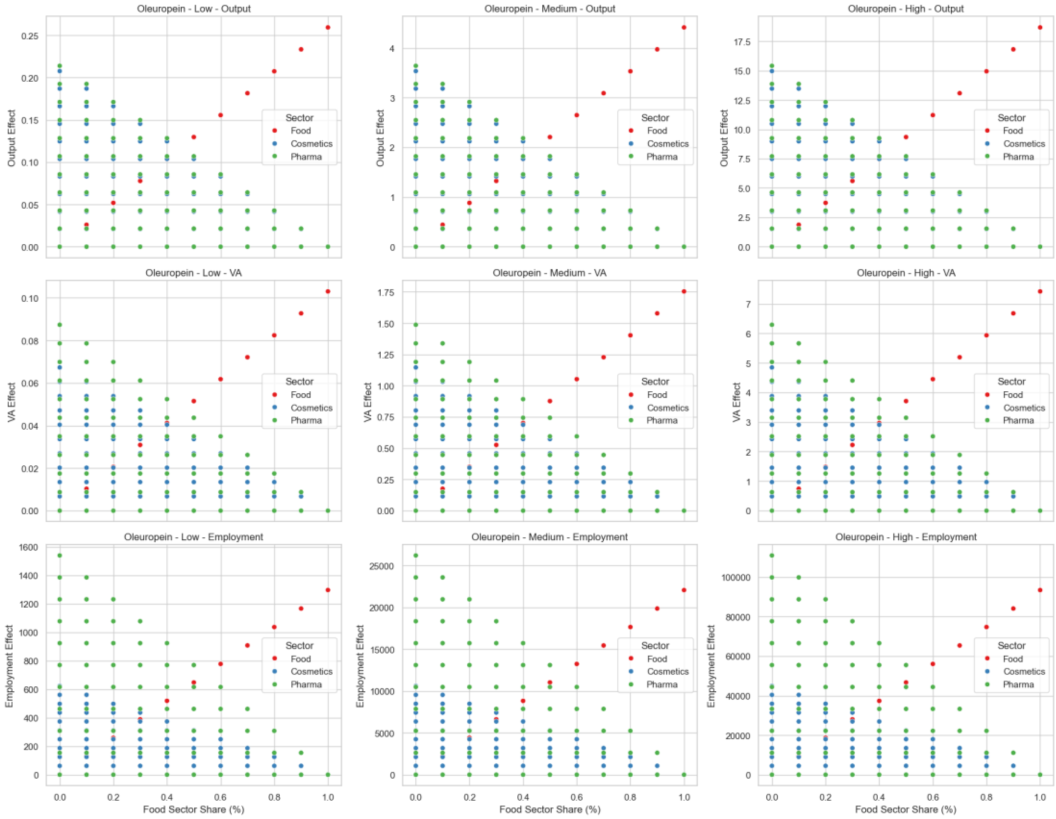

Figure 23. Effect of Sectoral Share by Scenario and Metric – Oleuropein

The analyses presented in Figures 19-23 reveal that the economic response of each extract type to sectoral distribution varies significantly depending on both the extract's characteristics and the scenario level (low, medium, high production). Overall, the food sector stands out in terms of both output and value added impacts, particularly in the high production scenarios. In contrast, the pharmaceutical sector, particularly for extracts such as resveratrol and lycopene, yielded notable employment impacts. The cosmetics sector, by providing a balanced contribution from some extracts, has reached a competitive level in terms of value-added and employment impacts, particularly in multi-purpose extracts such as oleuropein and tocopherols. It is understood that the economic impacts increase across all sectors as the scenario level increases, but this increase is more pronounced in the food sector.

The scatter plot analyses presented in Figures 19-23 graphically illustrate how each extract responds to different sector distributions, allowing for a visual assessment of the impact of sectoral trends on economic outputs. However, these visuals provide a limited summary for decision support processes due to the wide range of variation generated by hundreds of scenarios. Therefore, summary tables representing the minimum, mean, and maximum values of output, value-added, and employment impacts for each extract and scenario combination were prepared (Tables 33-37). These tables indicate the sectoral distribution (e.g., 30% food / 50% cosmetics / 20% pharmaceuticals) that achieves each effect and are presented along with the relevant final demand shock value.

Table 33. Effect of Sectoral Share by Scenario and Metric – Bulk Extract

Extract	Scenario	Effect Type	Final Demand Shock (Million $)	Sectoral Share (F/C/P)	Output Effect (M$)	Value Added Effect (M$)	Employment Effect (Person)
Bulk extract	High	Employment	2019.00	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	3141.88 / 3198.14 / 3235.64	1018.12 / 1200.08 / 1321.39	9425652 / 17748210 / 23296582
Bulk extract	High	Output	2019.00	0% - 100% - 0% / 30% - 50% - 20% / 100% - 0% - 0%	3141.88 / 3394.95 / 3922.92	1018.12 / 1240.87 / 1558.43	9425652 / 15256525 / 19614610
Bulk extract	High	Value Added	2019.00	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	3141.88 / 3354.34 / 3922.92	1018.12 / 1308.14 / 1558.43	9425652 / 19786001 / 19614610
Bulk extract	Low	Employment	0.40	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	0.62 / 0.63 / 0.64	0.20 / 0.24 / 0.26	1865 / 3512 / 4610
Bulk extract	Low	Output	0.40	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.62 / 0.67 / 0.78	0.20 / 0.25 / 0.31	1865 / 3293 / 3882
Bulk extract	Low	Value Added	0.40	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.62 / 0.66 / 0.78	0.20 / 0.26 / 0.31	1865 / 3915 / 3882
Bulk extract	Medium	Employment	77.58	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	120.73 / 122.89 / 124.33	39.12 / 46.11 / 50.78	362193 / 681998 / 895201
Bulk extract	Medium	Output	77.58	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	120.73 / 130.82 / 150.74	39.12 / 48.85 / 59.88	362193 / 639552 / 753717
Bulk extract	Medium	Value Added	77.58	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	120.73 / 128.89 / 150.74	39.12 / 50.27 / 59.88	362193 / 760303 / 753717

The findings in Table 33 indicate that in the High scenario, with a $2 billion shock, the output effect would range from $3142–$3923 million, value added from $1018–

$1558 million, and employment from 9.4–19.6 million. Even in extreme scenarios like 100% food or 100% pharmaceutical, significant effects were observed in sector shares. It is particularly noteworthy that in the Value Added scenario, despite a 60% weighting of pharmaceuticals in the median distribution, the value added effect reaches its maximum. In the Medium scenario ($77.58 million shock), the effects are dramatically reduced but still significant. Output would range from $120–$150 million, and employment would range from 362–895 million. In the Low scenario, output would be pretty limited, but even in this scenario, the impact of several million dollars and thousands of jobs is striking.

Table 34. Effect of Sectoral Share by Scenario and Metric – Lycopene

Extract	Scenario	Effect Type	Final Demand Shock (Million $)	Sectoral Share (F/C/P)	Output Effect (M$)	Value Added Effect (M$)	Employment Effect (Person)
Lycopene	High	Employment	157.50	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	245.09 / 249.48 / 252.40	79.42 / 93.62 / 103.08	735272 / 1384495 / 1817310
Lycopene	High	Output	157.50	0% - 100% - 0% / 30% - 50% - 20% / 100% - 0% - 0%	245.09 / 264.83 / 306.02	79.42 / 96.80 / 121.57	735272 / 1190124 / 1530088
Lycopene	High	Value_Added	157.50	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	245.09 / 261.66 / 306.02	79.42 / 102.05 / 121.57	735272 / 1543458 / 1530088
Lycopene	Low	Employment	0.00	0% - 90% - 10% / 10% - 30% - 60% / 0% - 0% - 100%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	6 / 11 / 14
Lycopene	Low	Output	0.00	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	6 / 10 / 12
Lycopene	Low	Value_Added	0.00	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	6 / 11 / 12
Lycopene	Medium	Employment	27.09	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	42.16 / 42.92 / 43.42	13.66 / 16.10 / 17.73	126484 / 238166 / 312620
Lycopene	Medium	Output	27.09	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	42.16 / 45.68 / 52.64	13.66 / 17.06 / 20.91	126484 / 223343 / 263211
Lycopene	Medium	Value_Added	27.09	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	42.16 / 45.01 / 52.64	13.66 / 17.55 / 20.91	126484 / 265511 / 263211

The findings in Table 34 show that in the High scenario, a shock of $157.5 million could generate $245–306 million in output, $79–122 million in value added, and employment between 0.74 and 1.82 million people. A balanced sectoral distribution at the median values (e.g., a 30%–50%–20% split in the Output scenario) optimized both output and employment. The maximum impact is noticeable in scenarios with 60% pharmaceutical value added. The Medium scenario, with a shock of $27.09 million, offers more limited but still significant output. It is particularly notable for its employment potential of 0.13–0.31 million people. In the Low scenario, the shock is considerably smaller than $1 million, appearing close to zero, and the results do not produce a significant impact. However, the ability to generate employment at a level of 6–14 people, even with a shock of just a few dollars, could be important for flexible applications.

Table 35. Effect of Sectoral Share by Scenario and Metric – Resveratrol

Extract	Scenario	Effect Type	Final Demand Shock (Million $)	Sectoral Share (F/C/P)	Output Effect (M$)	Value Added Effect (M$)	Employment Effect (Person)
Resveratrol	High	Employment	14.40	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	22.41 / 22.81 / 23.08	7.26 / 8.56 / 9.43	67231 / 126593 / 166169
Resveratrol	High	Output	14.40	0% - 100% - 0% / 30% - 50% - 20% / 100% - 0% - 0%	22.41 / 24.22 / 27.98	7.26 / 8.85 / 11.12	67231 / 108821 / 139906
Resveratrol	High	Value_Added	14.40	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	22.41 / 23.93 / 27.98	7.26 / 9.33 / 11.12	67231 / 141128 / 139906
Resveratrol	Low	Employment	0.00	0% - 80% - 20% / 0% - 30% - 70% / 10% - 0% - 90%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	3 / 5 / 7
Resveratrol	Low	Output	0.00	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	3 / 5 / 5
Resveratrol	Low	Value_Added	0.00	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	3 / 6 / 5
Resveratrol	Medium	Employment	0.36	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	0.56 / 0.57 / 0.58	0.18 / 0.21 / 0.23	1675 / 3154 / 4140

Table 35. continued

Resveratrol	Medium	Output	0.36	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.56 / 0.60 / 0.70	0.18 / 0.23 / 0.28	1675 / 2958 / 3486
Resveratrol	Medium	Value_Added	0.36	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.56 / 0.60 / 0.70	0.18 / 0.23 / 0.28	1675 / 3516 / 3486

The findings in Table 35 indicate that in the High scenario, a shock of $14.4 million could generate $22.4–28.0 million in output, $7.3–11.1 million in value added, and employment between 67.2 and 166.2 thousand people. In the pharmaceutical-heavy scenario (Value Added), value added reached its maximum with a 60% pharmaceutical contribution. In the Medium scenario, with a shock of $0.36 million, output ranged between $0.56 and 0.70 million, value added between $0.18 and 0.28 million, and employment between 1,675 and 4,140 people. In the Low scenario, the effects were minimal, with output and value added close to zero. However, depending on the application scale, employment impacts ranged between 3 and 7 people, which, although small, could still be meaningful in flexible applications.

Table 36. Effect of Sectoral Share by Scenario and Metric – Tocopherols

Extract	**Scenario**	**Effect Type**	**Final Demand Shock (Million $)**	**Sectoral Share (F/C/P)**	**Output Effect (M$)**	**Value Added Effect (M$)**	**Employment Effect (Person)**
Tocopherols	High	Employment	0.11	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	0.17 / 0.17 / 0.17	0.05 / 0.06 / 0.07	498 / 937 / 1.230
Tocopherols	High	Output	0.11	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.17 / 0.18 / 0.21	0.05 / 0.07 / 0.08	498 / 879 / 1035
Tocopherols	High	Value_Added	0.11	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.17 / 0.18 / 0.21	0.05 / 0.07 / 0.08	498 / 1045 / 1035
Tocopherols	Low	Employment	0.00	0% - 100% - 0% / 0% - 30% - 70% / 0% - 0% - 100%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	8 / 15 / 19
Tocopherols	Low	Output	0.00	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	8 / 14 / 16

Table 36. continued

Tocopherols	Low	Value_Added	0.00	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	8 / 17 / 16
Tocopherols	Medium	Employment	0.04	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	0.06 / 0.06 / 0.06	0.02 / 0.02 / 0.02	166 / 312 / 410
Tocopherols	Medium	Output	0.04	0% - 100% - 0% / 30% - 50% - 20% / 100% - 0% - 0%	0.06 / 0.06 / 0.07	0.02 / 0.02 / 0.03	166 / 269 / 345
Tocopherols	Medium	Value_Added	0.04	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.06 / 0.06 / 0.07	0.02 / 0.02 / 0.03	166 / 348 / 345

The findings in Table 36 are for Tocopherols tested with the lowest final demand shocks. In the High scenario, a $0.11 million shock was applied, which generated $0.17–0.21 million in output, $0.05–0.08 million in value added, and employment of 498–1,230 people. This demonstrates that small and medium-sized enterprises, in particular, can create jobs even with low investment values. In the Medium scenario, with a shock of approximately $0.04 million, an output of $0.06–0.07 million and value added of $0.02–0.03 million were achieved. Employment impacts ranged from 166 to 410 people. In the Low scenario, the effects were minimal, with output and value added close to zero. However, depending on sectoral distribution, employment impacts were still between 8 and 19 people, indicating that even marginal investments can generate measurable employment effects.

Table 37. Effect of Sectoral Share by Scenario and Metric – Oleuropein

Extract	**Scenario**	**Effect Type**	**Final Demand Shock (Million $)**	**Sectoral Share (F/C/P)**	**Output Effect (M$)**	**Value Added Effect (M$)**	**Employment Effect (Person)**
Oleuropein	High	Employment	9.61	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	14.96 / 15.23 / 15.41	4.85 / 5.71 / 6.29	44884 / 84514 / 110935
Oleuropein	High	Output	9.61	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	14.96 / 16.21 / 18.68	4.85 / 6.05 / 7.42	44884 / 79255 / 93402
Oleuropein	High	Value_Added	9.61	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	14.96 / 15.97 / 18.68	4.85 / 6.23 / 7.42	44884 / 94218 / 93402
Oleuropein	Low	Employment	0.13	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	0.21 / 0.21 / 0.21	0.07 / 0.08 / 0.09	623 / 1173 / 1540
Oleuropein	Low	Output	0.13	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	0.21 / 0.23 / 0.26	0.07 / 0.08 / 0.10	623 / 1100 / 1297

Table 37. continued

Oleuropein	Low	Value_Added	0.13	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	0.21 / 0.22 / 0.26	0.07 / 0.09 / 0.10	623 / 1308 / 1297
Oleuropein	Medium	Employment	2.27	0% - 100% - 0% / 0% - 40% - 60% / 0% - 0% - 100%	3.54 / 3.60 / 3.64	1.15 / 1.35 / 1.49	10605 / 19970 / 26213
Oleuropein	Medium	Output	2.27	0% - 100% - 0% / 30% - 40% - 30% / 100% - 0% - 0%	3.54 / 3.83 / 4.41	1.15 / 1.43 / 1.75	10605 / 18727 / 22070
Oleuropein	Medium	Value_Added	2.27	0% - 100% - 0% / 20% - 20% - 60% / 100% - 0% - 0%	3.54 / 3.77 / 4.41	1.15 / 1.47 / 1.75	10605 / 22263 / 22070

The findings in Table 37 show that the oleuropein scenarios have a balanced performance, particularly in terms of employment and value added. In the High scenario ($9.61 million shock), the output impact ranges between $14.96 and $18.68 million, while value added is between $4.85 and $7.42 million. Employment impacts are significant, ranging from 44,884 to 110,935 people. The Medium scenario presents lower but still notable effects, with an output impact of $3.54–4.41 million, value added between $1.15 and $1.75 million, and employment ranging from 10,605 to 26,213 people. In the Low scenario, with a shock value of $0.13 million, the output impact is limited to $0.21–0.26 million, value added to $0.07–0.10 million, and employment between 623 and 1,540 people.

As a result, bulk extract scenarios, in particular, have demonstrated the potential to generate billions of dollars in output and added value thanks to high production volumes and widespread sector use, while also generating employment opportunities for millions of people. Extracts with more specialized ingredients (lycopene, oleuropein, resveratrol, tocopherols) produced more modest but significant impacts depending on sector distribution and scale, with the value-added effect reaching its maximum in scenarios focused on the pharmaceutical sector. The Medium and Low scenarios offered alternatives that do not require high investment and are applicable at the local or regional level, supporting employment and boosting economic vitality.

A sensitivity analysis was conducted further to examine sectoral impacts (Figures 24-28). In this context, in scenarios where total revenue was held constant, the share allocated to the food sector was increased from 0% to 100%, with the remaining revenue distributed equally among the cosmetics and pharmaceutical sectors.

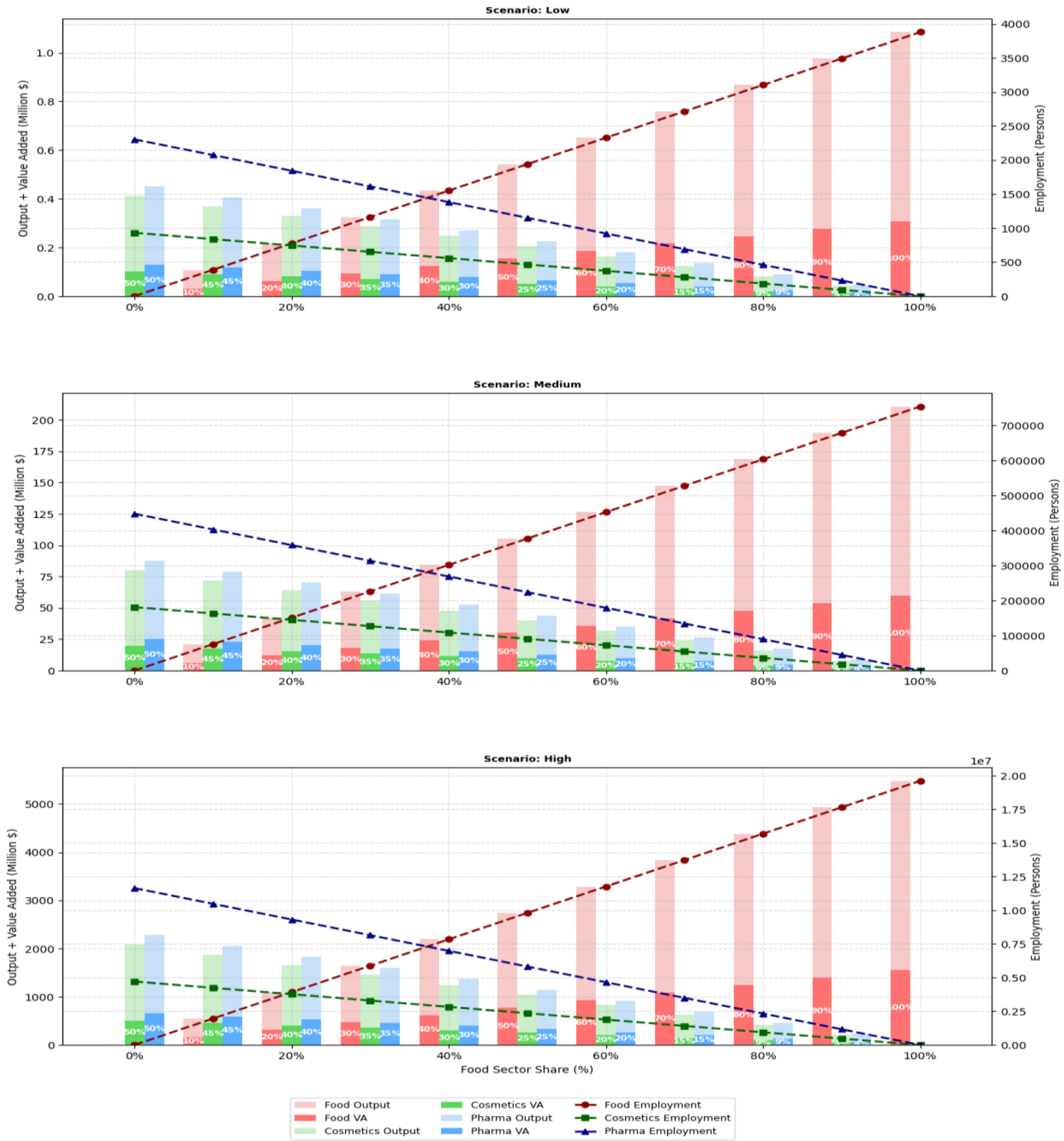

Figure 24. Food Sector Share Impact on Output, Value Added, and Employment-Bulk Extract

The findings in Figure 24 show that, in all three scenarios, increased diversification into the food sector significantly increases total economic output and employment. In particular, the High scenario, with a 100% diversification into food, yields an economic impact exceeding $5 billion and employment impacts of nearly 20 million people. In contrast, the contribution of the cosmetics and pharmaceutical sectors was limited, particularly in terms of employment, due to their lower employment coefficients. For example, even with a 20–40% diversification into food, the employment impact of the food sector reached the level of the cosmetics and pharmaceutical sectors, respectively. Conversely, the cosmetics and pharmaceutical sectors, with the same level of diversification, failed to generate as much employment as the food sector.

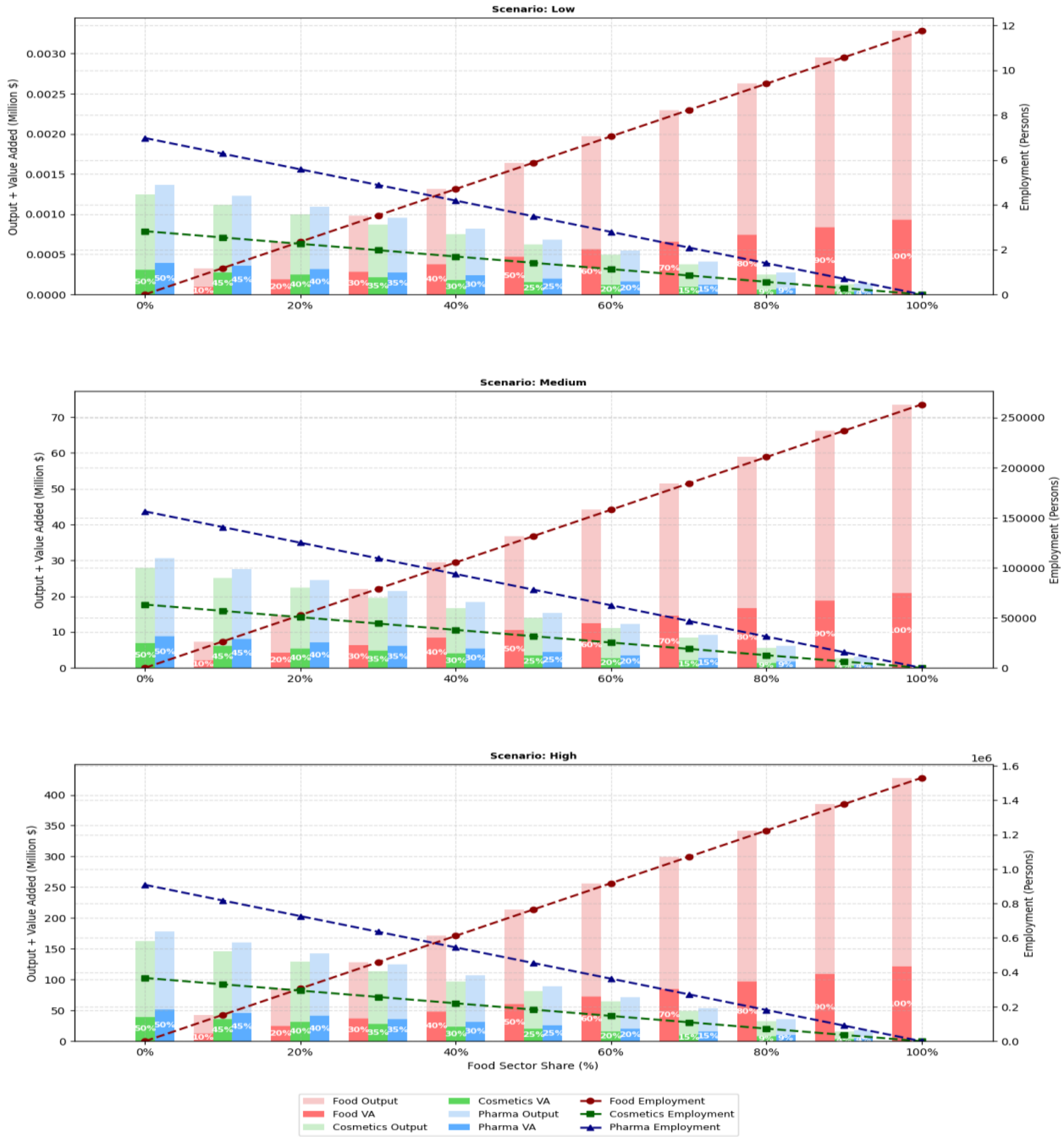

Figure 25. Food Sector Share Impact on Output, Value Added, and Employment-Lycopene

The findings in Figure 25 show that total economic output and employment increase significantly with increased focus on the food sector in all three scenarios. This demonstrates that the food sector's employment multiplier is much higher and that it plays a dominant role in the total employment impact as its share increases in all three scenarios. For example, in the High scenario, a 100% share for food would generate approximately 1.5 million jobs, while this figure is much more limited in other sectors. Furthermore, when food shares reach 20% and 40%, employment outcomes similar to those in the cosmetics and pharmaceutical sectors are observed. This demonstrates that the food sector can maintain its strong employment contribution even with lower shares.

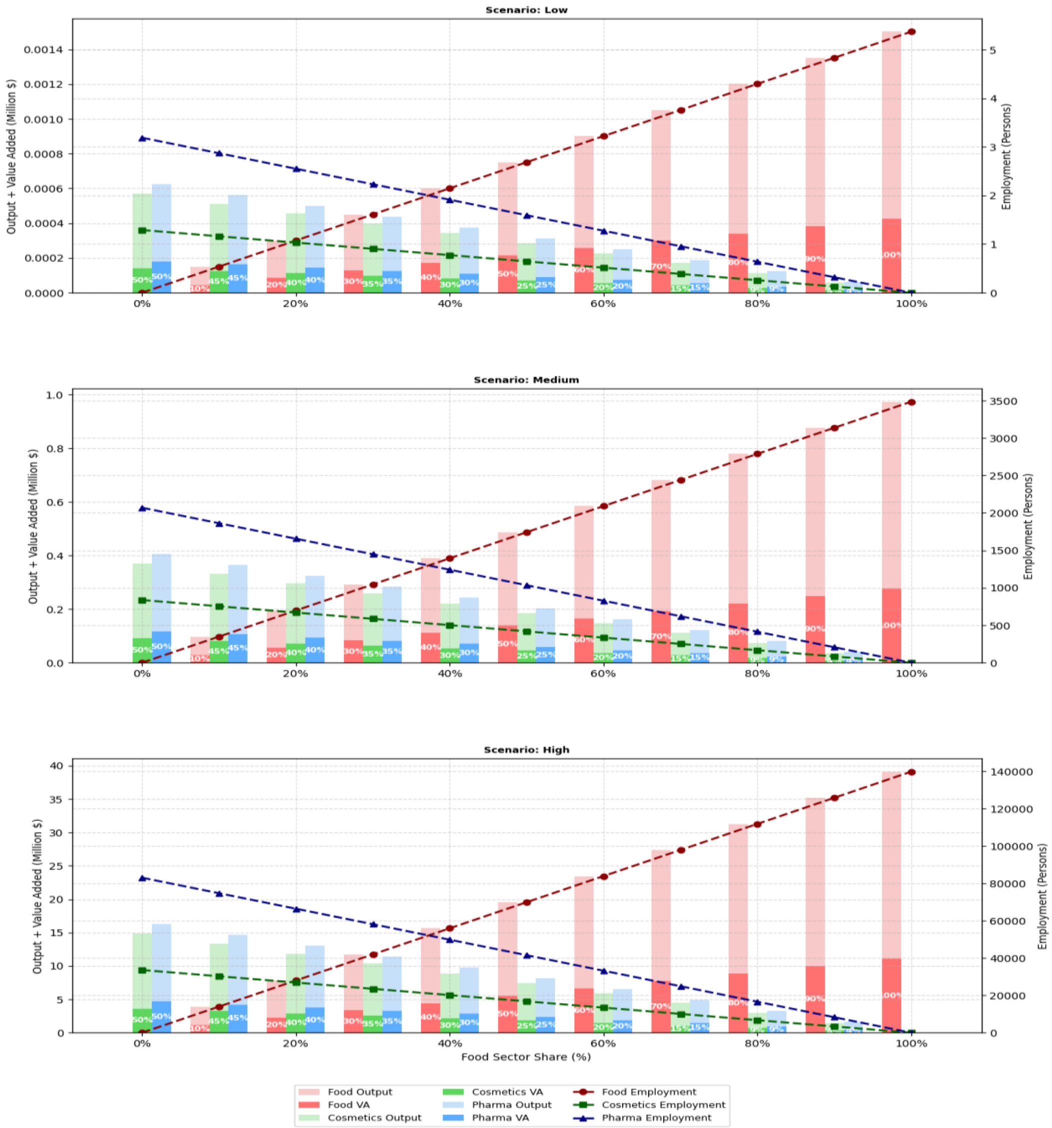

Figure 26. Food Sector Share Impact on Output, Value Added, and Employment-Resveratrol

The findings in Figure 26 show that total economic output and employment increase significantly in all three scenarios as the food sector increases. With a 100% share allocated to food, the Low scenario calculates an employment contribution of 5 people, the Medium scenario 3,500, and the High scenario 140,000. A 20% share of food yields employment levels similar to the cosmetics sector, and a 40% share similar to the pharmaceutical sector. This demonstrates that the food sector has a high employment generation capacity, even at lower shares.

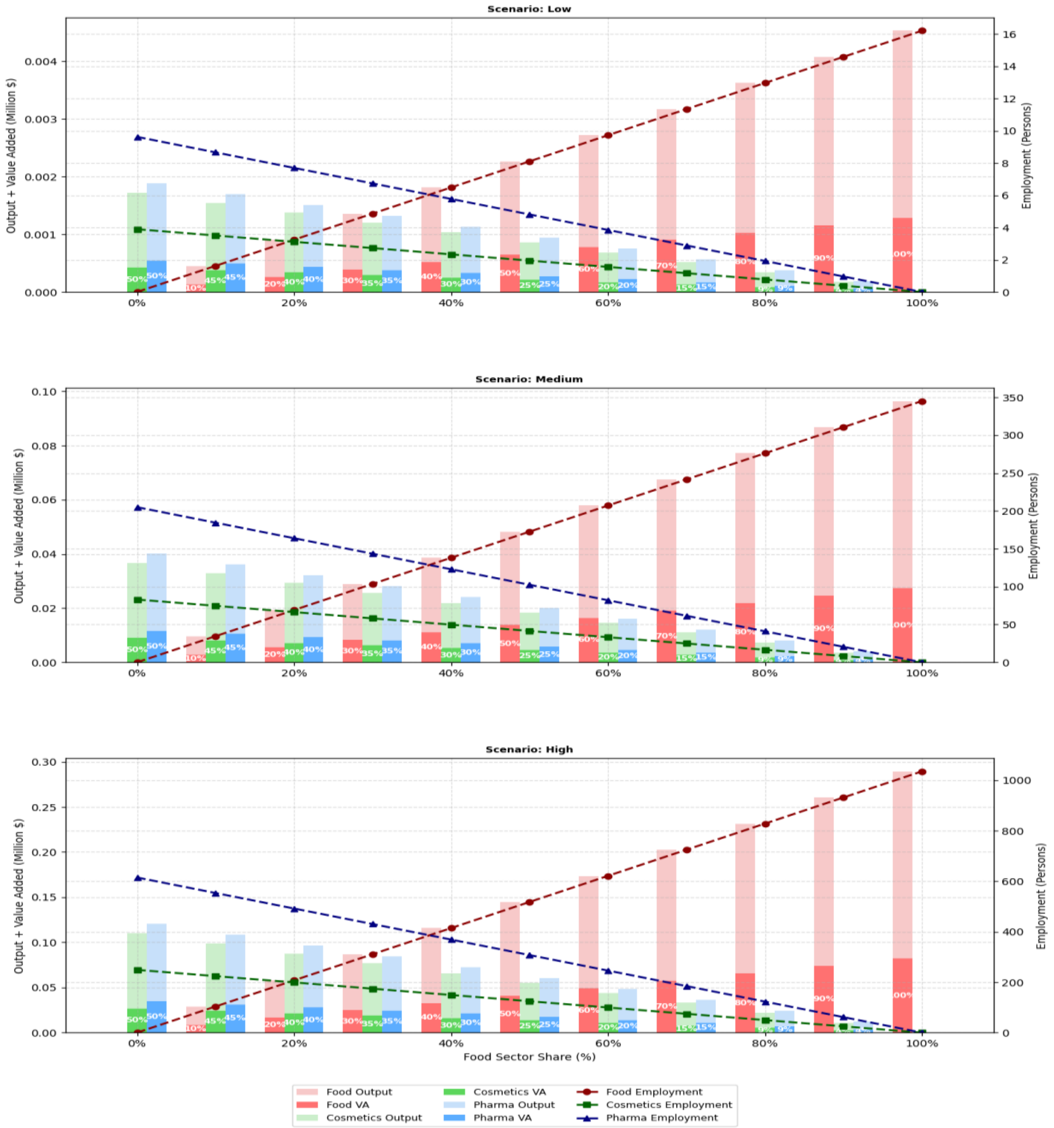

Figure 27. Food Sector Share Impact on Output, Value Added, and Employment-Tocopherols

The findings in Figure 27 show that when the food sector is assigned a 100% allocation in the High scenario, total output reaches $0.29 million and employment reaches 1,020. In contrast, when the food sector's share is 0%, total employment remains at only around 540 people. Employment generated by a 20% food share is equivalent to that generated by the cosmetics sector. In comparison, employment generated by a 40% food share is equivalent to that generated by the pharmaceutical sector alone. These findings indicate that the food sector has the most substantial impact on employment. However, the cosmetics and pharmaceutical sectors also make significant contributions in terms of value added and output. The pharmaceutical sector, in particular, maintains a stable and high level of economic output despite its lower employment contribution.

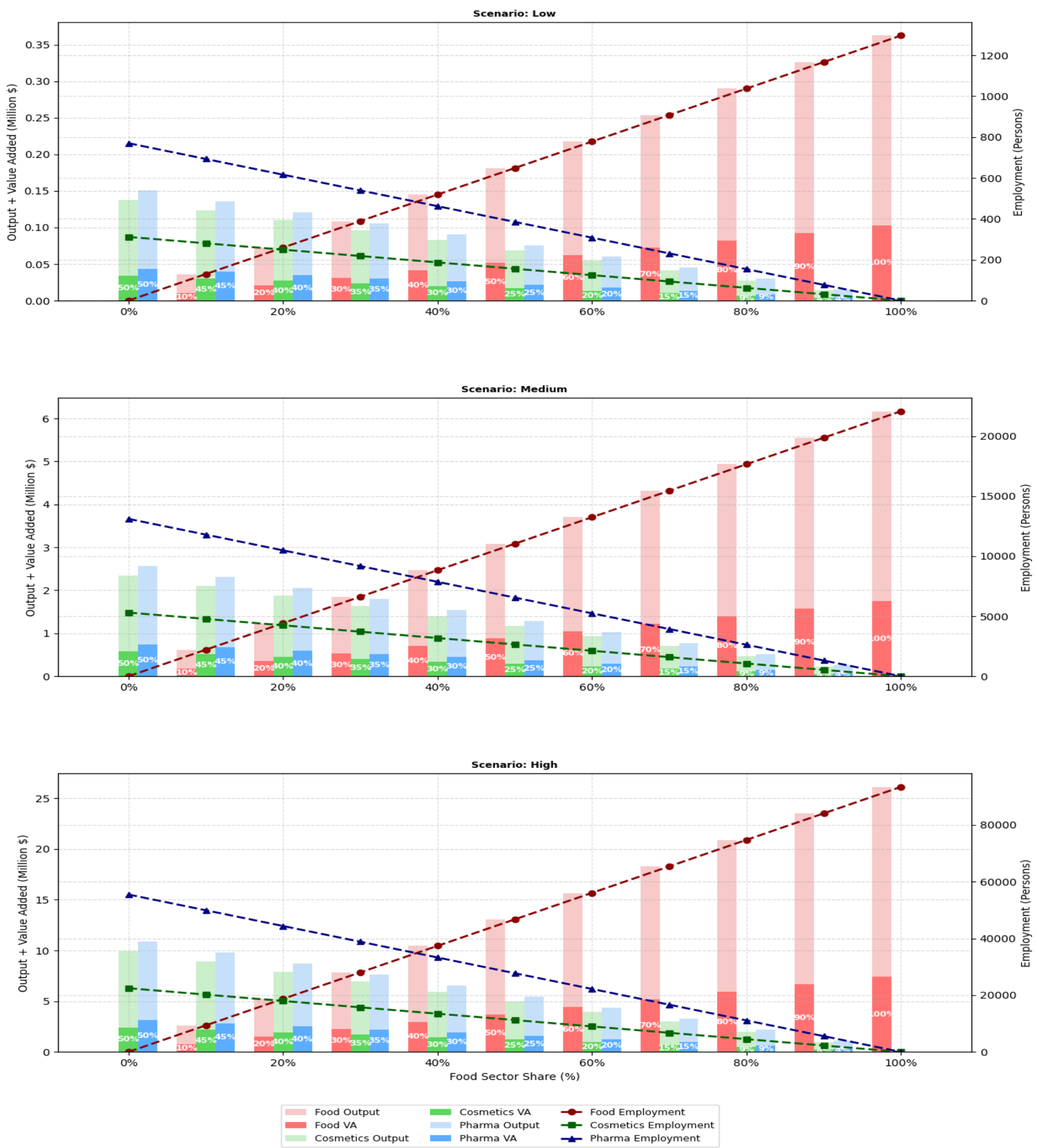

Figure 28. Food Sector Share Impact on Output, Value Added, and Employment-Oleuropein

The findings in Figure 28 show that increasing the allocation to the food sector significantly increases total economic output and employment in all three scenarios. In the Low scenario, 100% allocation to food resulted in an economic output of approximately $0.35 million and an employment impact of 1,250 people. In the High scenario, 100% allocation to food resulted in an economic contribution of approximately $25 million and employment of approximately 85,000 people. As the share allocated to the food sector increases, the contributions of the cosmetics and pharmaceutical sectors decrease. However, the pharmaceutical sector, in particular, is observed to provide high value-added. In terms of employment, at 20% and 40% food shares, the employment impact is similar to that of the cosmetics and pharmaceutical sectors, respectively.

Sensitivity analyses (Figure 24-28) demonstrated the decisive impact of diversification into the food sector on both economic output and employment. Across all production scenarios (low, medium, and high), it was observed that the total economic contribution and employment created increased significantly with an increase in the share allocated to the food sector. Especially when a share exceeding 30% was allocated to the food sector, the food sector contributed more in terms of both production output and value added for all extract types (bulk extract, lycopene, resveratrol, tocopherol, etc.) compared to the cosmetics and pharmaceutical sectors.

In terms of employment, the food sector's multiplier coefficient is much higher than that of other sectors. This means that even with relatively limited diversification of only 20–40% to the food sector, the employment created by this sector reached levels equivalent to the total employment impact of the cosmetics and pharmaceutical sectors.

On the other hand, despite their lower employment impact, the cosmetics and pharmaceutical sectors demonstrated a powerful performance in terms of economic output and value added. The contribution of these sectors, especially in the production of high value-added products, has played a critical role in maintaining economic diversity and increasing overall productivity.

CHAPTER 6

DISCUSSION

6.1. Evaluation of the AR Profile: Turkish Literature and Monte Carlo Analysis

In this study, a Monte Carlo simulation method was applied, taking into account product-based uncertainties, to demonstrate Türkiye's AW potential. Sensitivity analysis showed that the simulations were reliable, with 6,000 iterations yielding deviations below 1%. The simulation outputs (see Table 21) revealed an annual average of 105 million tons of theoretical residue, 70 million tons of theoretical dry residue, approximately 50 million tons of collectable theoretical residue, and approximately 30 million tons of collectable dry residue across Türkiye for 132 agricultural products. While field residue accounts for approximately 78% of theoretical residue, this percentage decreases to approximately 63% at the collectable residue stage. This difference is related to the low collectability of field residue due to logistical reasons. When moisture content is taken into account, the share of field residue in total theoretical dry residue increases again due to its lower moisture content, reaching approximately 77%. On the other hand, due to its low collectability, its share in collectable dry residue decreases to 55%. In contrast, agro-industrial residues have higher collectability rates because they are generated more systematically in factories or processing centres. However, these residues generally have higher moisture content than field residues. When moisture content is taken into account, field residues account for around 23% of the total theoretical dry residue, while their share of collectable dry residue is around 44%. The study results were compared and evaluated with various national-scale studies conducted in Türkiye.

According to BEPA data, an annual collectable AR potential of approximately 62 million tons is projected for 108 different crops. Based on agricultural production and RPR values provided by BEPA, an average calculation for the 81 crops included in this study reveals a collectable residue potential of approximately 50 million tons. For the 81 products considered in this study (the number of products included in field residue), a potential for collectable AR of approximately 31 million tons was calculated, of which approximately 17 million tons were identified as collectable dry residue. Considering that BEPA uses fixed RPR values and reflects ideal conditions, the more conservative estimates in this study appear to stem from a distributional modelling approach.

Avcıoğlu et al. (2019) calculated approximately 50 million tons of dry field residue for 28 different products based on 2015 production data. Simulations for the same 28 products in this study yielded an estimate of approximately 54 million tons of dry field residue. However, it is noteworthy that despite a 35% increase in production volume, the increase in dry field theoretical residue amount was only 8%. This suggests that a non-linear increase in residue potential is not observed due to not only increased production but also changes in product composition and the variance of factors such as RPR. This difference is also indicative of the conservative estimate obtained through the distributional modelling used in this study.

Bahadıroğlu et al. (2022) divided AR into two categories: primary (PR) and secondary (SR). They reported that approximately 40 million tons of PR and approximately 7 million tons of SR are generated annually in Türkiye. Bahadıroğlu's study was based on fixed and often considered high RPR rates. In this study, RPR, industrial processing rate, and by-product rates were modelled distributionally using different literature ranges for each product, thus incorporating uncertainty and product-based variations into the simulation. These differences significantly altered the total estimated values. In this study, the average amount of dry residue corresponding to SR was estimated to be approximately 5 million tons.

In a study conducted by Ünal et al. (2007) on 33 crops, approximately 43 million tons of dry field residue were estimated annually using constant yield coefficients. In this study, calculations using the distributional RPR model for the same crop group yielded approximately 18 million tons of field residue. This approximately 2.3-fold difference demonstrates that methods based on constant coefficients are limited in terms of sensitivity to field conditions. At the same time, the distributional approach, which directly integrates mitigating factors such as moisture and collectability into the model, offers more cautious and realistic estimates.

Similarly, in a study conducted by Polat (2021) using the HI method, approximately 57 million tons of AR were estimated across Türkiye as of 2018. While the different assumptions used by the HI and RPR methods make direct comparison difficult, the similarities in the estimates are striking.

In conclusion, the distributional and uncertainty-based modelling approach presented in this study allows for a qualitative understanding of Türkiye's AR potential, both quantitatively and qualitatively. Going beyond traditional approaches based on fixed rates, this method takes into account variation among crops. It integrates field-specific parameters such as collectability and moisture content into the model, producing more realistic outputs suitable for decision-making processes. In this respect, the study provides a forecasting framework that is sensitive to field conditions and suitable for application in terms of both resource planning and strategic prioritization.

6.2. Multi-Criteria Decision Assessment: Evaluation of AHP-TOPSIS Results

In this study, a systematic literature review was conducted on SFE and bioactive compound production (see Section 5.2). Data were retrieved from the academic databases Scopus, Web of Science, ScienceDirect, PubMed, and Springer Nature. From a total of 2,530 articles, 790 unique articles containing at least one AR reference were identified, and 124 different product- residue pairs were generated from these studies. SFE Score and Bioactive Score were assigned to each pair based on the level and quality of SFE and bioactive compound studies.

The SFE Score and Bioactive Score indicators not only measure the level of literature presence but also reveal which product- residue pairs have the strongest scientific and technological foundation. However, literature representation alone is not sufficient for prioritization, as high scores that do not align with field data may also be associated with low-volume or difficult-to-collect residues in practice. Therefore, the volume of product-based waste and the level of uncertainty were integrated into the decision-making process, along with the literature density.

Pairwise comparisons were made between the criteria using the AHP method, and relative weights were calculated (See Section 5.3). The highest weight (approximately 55%) was given to the Bioactive Score because the primary focus of this study is the production of bioactive compounds, and the functionality and marketability of the products are directly related to this score. Second priority (25%) was given to the SFE Score because this criterion represents technical feasibility and process reproducibility. AR amount and CV Ratio were each weighted at 10%. The lower weighting for these two criteria was to prevent high-volume but low-functionality residue from being overweighted in the model. Similarly, this criterion was kept balanced to avoid completely excluding products with high CV.

The resulting AHP weights were integrated with the TOPSIS method, and the degree of closeness to the ideal solution was calculated for each product- residue pair—the TOPSIS ranking prioritized grape, tomato, and olive products. The main reasons for these products' high rankings are that they have been frequently studied in the literature for both SFE and bioactive compound production, and that their processable residue volumes are also significant. Conversely, some products, despite having a high residue potential (e.g., field residues with high lignocellulose content, such as wheat straw), are ranked lower due to the lack of studies in the literature related to bioactive compounds or SFE.

This suggests that these product groups have not been adequately researched within the scope of SFE or are being utilized primarily in energy-based applications such as incineration, gasification, pyrolysis, or biogas production rather than bioactive compound production. Indeed, the literature indicates that residue from high-volume field crops such as wheat, corn, and barley is often used in energy conversion systems (Adıgüzel, 2013; Melikoğlu, 2011; Özütemiz, 2017; Fidan & Alkan, 2014; Çolakoğlu, 2018).

On the other hand, exploring new SFE-based application areas for agro-industrial residue generated under more controlled conditions in factories represents a significant gap in both the scientific literature and investment strategies. In this context, evaluating a broader range of agro-industrial residue, particularly fruit and vegetable processing waste, from an SFE perspective could offer new opportunities at both academic and industrial scales.

The AHP–TOPSIS-based multi-criteria decision model proposed in this thesis goes beyond simply ranking products prominent in the literature and aims to provide a feasible prioritization compatible with the current AR profile in Türkiye. The model holistically considers four key criteria: the applicability of SFE, bioactive compound potential, residue quantity, and uncertainty level, thus evaluating both scientific knowledge and field reality within the same framework.

This approach not only identifies products with strong literature support but also highlights some residue types that have been studied only to a limited extent to date, despite their high production volume and convenient collectability. For example, residues such as tomato peels and grape seeds possess high SFE Score and Bioactive Score, as well as a significant amount of processable residue volume. Conversely, residues such as orange peel, apple pomace, cherry pits, and banana peels, although less represented in the literature, are ranked mid-range in the model and are among the most promising candidates (see Table 24). Furthermore, despite their relatively low residue content, pumpkin seeds and peels, and avocado seeds and pulp, stand out in the rankings thanks to their high SFE and bioactive compound studies.

For the subsequent stages of this study, the analysis was narrowed by selecting grape (pulp and seeds), tomato (pulp, peel, and seeds), and olive (pruning) residues as priority AWs. To test the robustness of this prioritization, a sensitivity analysis was conducted through three alternative AHP scenarios: a literature-oriented model assigning higher weights to the SFE Score and Bioactive Score, a supply-oriented model emphasizing residue availability and CV ratio, and a balanced model assuming equal weights for all criteria. The comparison showed that grape, tomato, and olive residues consistently ranked at the top under bioactive-based, literature-oriented, and balanced approaches. Conversely, the supply-oriented scenario shifted the priority toward high-volume but less studied residues such as wheat and maize. This finding demonstrates both the resilience of grape, tomato, and olive residues as strong candidates and the decisive role of decision-making perspectives in shaping residue prioritization outcomes.

Therefore, the model not only provides a ranking that reflects current conditions but also highlights AR types with potential for the future. In this respect, it may be advisable to evaluate agro-industrial residues such as citrus peels or apple pomace, which have high residue potential but limited bioactive compound studies, for both scientific and commercial investment in the future. Such decision-support models, widely used in the literature, particularly in areas such as biofuels, biodiesel, and environmental planning, are combined for the first time in this study with a bioactive compound-focused SFE assessment, enabling a more systematic analysis of local production potential.

6.3. Evaluation of Economic Scenarios and Input–Output Based Sectoral Analysis

Within the scope of the study, production scenarios were defined for a total of seven different residue types, including grape, tomato, and olive products, selected from prioritized ARs using AHP-TOPSIS analysis. Three distinct scenarios were defined for these residues, corresponding to low, medium, and high production volumes. These scenarios, representing pilot, realistic, and comprehensive scales, model different production levels in terms of processing volume, process capacity, and market scale.

For each scenario, the amount of extract that could be obtained from the prioritized residues was calculated based on yield ranges reported in the literature. These calculations determined production outputs based on minimum, average, and maximum yield values, and the total annual extract production potential for each product-residue pair was determined. Significant variability in extract yields was observed, particularly for products with wide yield ranges. For example, for some residues, such as olive pulp, the difference between the minimum and maximum yield values was more than twofold. In contrast, for products like tomato peels, this difference was lower (See Tables 27-28). This situation differentiates the impact of yield on scenario performance by product, necessitating the evaluation of economic forecasts with uncertainty levels.

Total revenue values calculated from production scenarios are closely related not only to the extract volume but also to the literature prices of the bioactive components contained in the products. For example, grape pomace extract stands out with its high price despite its low production volume. In contrast, high-volume and relatively low-priced residues like tomato pomace provided advantages in terms of total revenue (See Tables 29-30). This necessitated a strategic assessment based on the balance of high yield and low price, and low yield and high price.

When the revenue values obtained under each scenario were compared by product, it was determined that while the comprehensive scenario naturally yielded the highest revenue, the medium-scale scenario offered a more sustainable and accessible starting point for investment in Türkiye's conditions. In this scenario, extracts obtained from industrially integrated agro-industrial residues such as tomato pomace and olive pulp generated significant revenue streams thanks to both their high production volume and marketable component content. In particular, high-priced specific components have a significant impact on total revenue, despite their low production volumes. For example, oleuropein extract from olive pomace, despite representing only 1% of total production due to its high unit price, contributed close to 15% of total revenue. In contrast, the economic contribution of some specific components (e.g., resveratrol and lycopene) only became significant at high-scale production levels. While these components have low yields, their high prices have led to significant returns on aggregate with large production capacities. Therefore, small-scale pilot projects primarily focus on technology validation and product diversification. At the same time, medium- and large-scale scenarios offer a more strategic platform for economic scalability and return on investment.

The potential revenues calculated within the production scenarios were examined at the sectoral level to assess not only the economic return at the firm level but also the potential contributions to the national economy. In this context, I-O analysis was preferred for assessing economic impacts. This method allows for a holistic assessment of not only direct production revenues but also the secondary impacts created in the economy. Many micro-level feasibility studies are limited to product-based revenue or cost analysis; however, this approach ignores the knock-on effects of extract production and intersectoral interactions. I-O analysis fills this gap, numerically demonstrating the impact of extract production on output, value added, and employment in various sectors such as agriculture, food, cosmetics, and pharmaceuticals. Considering that investment planning, particularly in developing countries like Türkiye, must be shaped by multisectoral impacts, this analysis method offers decision-makers a more strategic perspective. Furthermore, the fact that multiplier effects vary depending on the sectors to which extracts are directed has enabled sector-based prioritization.

The relationship between the food sector and bioactive ingredients has already been emphasized in public strategy documents in Türkiye since 2022 (TÜBİTAK-TAGEM, 2022). According to multipliers calculated by evaluating Türkiye's 2022 I-O table together with sectoral employment data for the same year, the food sector has higher coefficients in terms of output and value-added generation capacity compared to the cosmetics and pharmaceutical sectors. In particular, the food sector's sensitivity to intermediate inputs and its labor-intensive production structure make the knock-on economic effects more widespread when production volume increases. Conversely, the pharmaceutical sector has higher coefficients in terms of output and value-added than the cosmetics sector, and higher coefficients in terms of employment than both the food and cosmetics sectors. This necessitates that sectoral guidance be evaluated not only in terms of production volume or total revenue, but also in terms of the type of economic impact. While diversification into the food sector has more widespread impacts in terms of total output and value-added growth, diversification into the pharmaceutical sector stands out in terms of skilled labor creation due to its high unit employment impact despite its limited production volume. The cosmetics sector, on the other hand, is more balanced in terms of both indicators but has lower multipliers (See Table 32).

The analysis was conducted based on scenarios targeting the food, cosmetics, and pharmaceutical sectors, and the production (output), value-added (value-added), and employment impacts were examined for each sector. Simulations were applied to three different production scenarios (low, medium, and high) for each product. Under these scenarios, sector shares were varied by 10%, and all probabilities were evaluated within the range of 0–100.

The analysis results show that the sectoral diversification of extracts creates a significant leverage effect on economic impacts (See Figure 18). The food sector, in particular, stood out as the sector with the highest output thanks to its high production and value-added multipliers. Similarly, scenarios focused on food offer the highest potential in terms of employment (See Figures 19-23). This is consistent with the C10–C12 sector representing both an employment-intensive and high-value-added structure in the Turkish economy. This suggests that integrating bulk extracts, which can be produced in high quantities but have lower specificity, into the food sector could yield more widespread economic benefits in the short term.

In contrast, while the cosmetics and pharmaceutical sectors offer high value-added potential in terms of specific ingredients, their widespread impact on the economy is lower due to their limited multiplier effects (See Figures 19-23). While the cosmetics sector generates a moderate impact in terms of production and value-added, its contribution to the workforce is limited due to its relatively low employment multiplier. However, considering this sector's export potential and brand value creation capacity, it can be considered a strategic steering tool. The pharmaceutical sector, on the other hand, while strong in terms of production and value-added, appears to have a more limited employment impact. This finding is consistent with the high-tech, capital-intensive structure of the C21 sector.

Graphical analyses (Figures 19–28) reveal how total impacts can be optimized by redistributing sector shares. For each production scenario, total output, value added, and employment impacts generally increase as the share allocated to food increases. However, these increases do not always follow a linear pattern. It has been observed that, particularly in the 20–40% food share range, by targeting food and other sectors together, total output, value added, and employment impacts can be maintained at levels relatively close to their maximum levels. For example, in the medium scenario for bulk extracts, if all production is directed solely to the food sector, the total output impact is calculated to be approximately $150 million, the value added impact is $60 million, and the employment impact is 753,717 jobs. However, in the same scenario, with a more balanced distribution of 30% to the food, 40% to the cosmetics, and 30% to the pharmaceutical sectors, these impacts amounted to approximately $131 million, $49 million, and 639,552 jobs, respectively (See Figure 19 and Table 33). This demonstrates that, rather than focusing on a single sector, a multisectoral focus can also yield significant economic benefits.

In conclusion, macroeconomic analyses reveal that extracts derived from AR represent not only a biotechnological production opportunity but also an instrument with strategic cross-sectoral impacts in terms of production, employment, and value-added generation. In this context, the determination of the sectors to which extracts will be directed should be evaluated not only from an economic size perspective but also based on factors such as development policies, employment structure, and social impact capacity.

Large-volume, low-unit-price extracts can generate widespread economic impacts by being directed to sectors with high output and employment multipliers, such as the food sector. At the same time, high-value-added but low-volume components can have more limited but more significant impacts in sectors such as pharmaceuticals and cosmetics. Therefore, the sectoral direction of bioactive ingredients derived from AR should be strategically planned, driven not only by economic benefits but also by social welfare and structural transformation objectives. To realize this potential, complementary factors such as the infrastructural capacity, regulatory adequacy, and market access of the relevant sectors must be considered. The findings provide a concrete and guiding basis for policymakers to plan agricultural bioeconomy strategies in Türkiye with a holistic approach.

CHAPTER 7

CONCLUSION

This thesis comprehensively examines the potential for converting field and agro-industrial wastes from agricultural production in Turkey into high-value-added bioactive compounds through SFE and analyzes the macroeconomic impacts of this conversion. The study redefines agricultural waste not merely as an environmental problem requiring disposal or a low-value energy source, but rather as a strategic input for the bioeconomy in the food, cosmetics, and pharmaceutical sectors. Thus, it offers an alternative perspective on the issue of agricultural waste, which has long been addressed in an energy-focused manner in Turkish literature, and highlights the economic and strategic importance of bioactive compound production at the national level.

A review of the existing literature in Turkey reveals that agricultural waste has been addressed mainly in the context of energy production for many years. While this approach is consistent with the country's high energy import dependency and renewable energy targets, the production of high-value-added biochemical compounds from waste has only recently begun to be addressed. Studies such as the 2022 TÜBİTAK-TAGEM report, in particular, demonstrate that awareness in this area is increasing. In contrast, the strategic importance of bioactive compounds is increasingly emphasized in international literature, and global demand for natural ingredients such as antioxidants, carotenoids, phenolic compounds, and sterols in the food, cosmetics, and pharmaceutical sectors is rapidly growing. In this context, this thesis bridges the gap between the energy-focused approach and the bioactive compound-focused approach, specifically in Turkey. It offers a unique methodological contribution to the literature through the integration of uncertainty modelling, multi-criteria prioritisation, and macroeconomic impact analysis.

In the first phase of the thesis, 285 product-waste pairs were identified for 132 agricultural products produced in Turkey, and their annual production potentials were calculated. Waste amounts were determined by considering product-based production data, product-waste ratios, industrial processing rates, moisture contents, and additivity coefficients. Monte Carlo simulation was applied to these calculations, including the uncertainties in the parameters, and probability distributions were obtained over 6,000 iterations. Simulation results showed that Turkey has an annual average of 105 Mt of theoretical waste, 50 Mt of collectable waste, and 30 Mt of dry collectable waste. In the minimum scenario, the amount of dry collectable waste decreases to 11 Mt. In contrast, in the maximum scenario, it increases to 75 Mt. This wide variation is primarily due to differences in moisture content and processing rates in agro-industrial waste. The findings reveal that Turkey, considering its agricultural diversity and production volume, possesses a vibrant resource not only for the energy sector but also for biotechnological transformation.

As a result of a systematic literature review, the SFE application conditions, extraction efficiencies, compound types obtained, and their application areas were compiled for each product-waste pair. Two separate scores were generated based on this data. The SFE Score reflects technical feasibility and literature support, while the Bioactive Score reflects compound diversity and functional value potential. These scores were evaluated using the AHP and TOPSIS methods, along with the waste quantities and CV obtained through Monte Carlo simulation. The analyses identified tomato peel, pulp, and seeds; grape pulp and seeds; olive pulp and pruning residue as priority waste groups. This finding demonstrates that products with high production volumes and strong SFE support in the literature stand out.

In the third phase of the study, three different processing capacity scenarios were developed for priority waste groups: 1,000 t/year pilot scale, 10,000 t/year medium scale, and 30,000 t/year commercial scale. Calculations based on these scenarios indicated that bulk extract production ranges from 0.1 to 4.5 kt/year, offering a revenue potential of USD 120 million to USD 1.5 billion. Among agro-industrial wastes, tomato pulp, grape pomace, and olive pulp stand out with their high-volume production potential. Specific compounds such as oleuropein, tocopherols, and lycopene have been shown to provide economic contributions of hundreds of millions of dollars, even at low tonnages. For example, lycopene is estimated to offer an annual revenue potential of USD 100–250 million, oleuropein approximately USD 120 million, and hydroxytyrosol USD 80–130 million. These results demonstrate that agricultural wastes represent a significant resource not only for high-volume production but also for compounds with low tonnage but high market value.

The Input-Output (I-O) method was used as part of the macroeconomic impact analysis, measuring the indirect impacts of revenues not only at the firm level but also at the national economy level. Calculations based on Turkey's 2022 sectoral I-O table and employment data were explicitly detailed for the food, cosmetics, and pharmaceutical sectors. The findings reveal that, in a medium-scale scenario, bulk extract production could contribute $400–800 million in total output, $150–300 million in added value, and 500–750,000 additional jobs to the Turkish economy. While the food sector stands out with its high output and value-added multipliers, the pharmaceutical sector attracted attention with its capacity to create a skilled workforce and high value-added potential. The cosmetics sector, with its more balanced but relatively low multiplier effects, was considered a complementary element of the system. However, the potential of specific compounds is also significant. It has been estimated that lycopene could reach an annual revenue potential of $100–250 million, oleuropein approximately $120 million, and hydroxytyrosol $80–130 million. Despite being produced in low tonnage, these compounds can contribute significantly to the economy, particularly in the pharmaceutical and cosmetics sectors, thanks to their high market value. Furthermore, sectoral distribution strategies have yielded different economic outcomes. In a medium-scale scenario, directing all production to the food sector would generate approximately $150 million in output, $60 million in added value, and 753,000 jobs. If 20% of production is directed to food, 40% to cosmetics, and 40% to pharmaceuticals, these contributions are estimated to be $128 million in output, $50 million in added value, and 653,000 jobs. This finding suggests that while multi-sectoral distribution may slightly reduce overall impacts, it also offers a structure more compatible with circular bioeconomy policies by increasing sectoral diversification and strategic balance.

While all these findings demonstrate the significant contributions of the study, they also present certain limitations. First, the RPR, moisture, and collectability rates used in calculating waste quantities vary across different sources, adding uncertainty to the results. Furthermore, yield data for specific compounds were obtained primarily at the laboratory scale, and it should be noted that process efficiency losses may occur at pilot and commercial scales. While revenue potentials were calculated in the study, capital, energy, labor, and logistics costs were not comprehensively considered. Similarly, potential fluctuations in market prices and increases in global demand were not directly reflected in the analysis. Indicators such as environmental impacts, carbon footprint, and greenhouse gas reduction were not evaluated within the scope of this thesis.

Several key areas for future research stand out. First, developing pilot-scale SFE applications for priority wastes will enable comparison of laboratory data with field conditions. Furthermore, conducting holistic cost analyses including capital and operating costs will contribute to more precise profitability calculations. Creating a dynamic inventory of agricultural wastes in Turkey, systematically including agro-industrial wastes and integrating regional differences will facilitate more realistic projections. Updating existing databases such as BEPA and restructuring them with a bioeconomy perspective is crucial. From a regulatory perspective, existing legislation (e.g., Law No. 5996, the Food Supplements Regulation, the Health Declaration Regulation, and the Traditional Herbal Medicinal Products Licensing Regulation) provides a basic framework. However, developing specific quality standards for SFE-based extracts and establishing transparent, harmonized, and coordinated legislation for their use in food, pharmaceutical, and cosmetics sectors can be considered a critical development to increase investor confidence. Furthermore, from a rural development perspective, the effective involvement of agricultural cooperatives and producer associations in waste collection, drying, and transportation, as well as the expansion of clustering and shared-use models, can contribute to integrating small and medium-sized producers into the system, especially in SFE technologies with high investment costs.

In conclusion, this thesis has examined the technical, economic, and sectoral dimensions of converting agricultural waste into bioactive compounds through supercritical fluid extraction in Turkey, employing a holistic approach, and has demonstrated the potential for biotechnological transformation. The findings show that utilizing agricultural waste can foster diversification, increase employment, reduce import dependency, and build a model compatible with circular bioeconomy policies. In this context, bolstering Turkey's agricultural infrastructure with biotechnology can be considered a strategic opportunity not only for economic returns but also for strengthening rural development, sustainability, and social welfare.

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APPENDICES

A. MONTE CARLO SIMULATION: COMPLETE DATASET

Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_m in	IND_m ax	I_RPR_ min	I_RPR_ max	I_ AVAIL	I MOIST_m in	I_ MOIST_max	MC
Arable Crops	Wheat-Durum	Field	Straw	wheat	straw	0,5	2	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Wheat-Other	Field	Straw	wheat	straw	0,5	2	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Maize	Field	Stalk	maize	stalk	0,7	2,67	0,6	0,15	-	-	-	-	-	-	-	1
Arable Crops	Barley-Other	Field	Straw	barley	straw	0,75	1,14	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Barley-Other	Field	Stalk	barley	stalk	1	1,6	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Barley-Beer	Field	Straw	barley	straw	0,75	1,14	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Barley-Beer	Field	Stalk	barley	stalk	1	1,6	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Rye	Field	Straw	rye	straw	0,99	1,6	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Oats	Field	Straw	oat	straw	1	1,5	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Sorghum	Field	Stalk	sorghum	stalk	1,4	2,62	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Millet	Field	Straw	millet	straw	1,4	3	0,15	0,15	-	-	-	-	-	-	-	1
Arable Crops	Chick Peas-Dry	Field	Straw	chick pea	straw	1,1	1,3	0,1	0,9	-	-	-	-	-	-	-	1
Arable Crops	Chick Peas-Dry	Field	Stem, Leave	chick pea	stem, leave	2,27	2,27	0,1	0,9	-	-	-	-	-	-	-	1
Arable Crops	Lentils-Dry,Red	Field	Stem, Leave	lentil	stem, leave	1,67	1,67	0,1	0,9	-	-	-	-	-	-	-	1

Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_ min	IND_ max	I_RPR _min	I_RPR _max	I_ AVAIL	I MOIST_ min	I_ MOIST_ max	MC
Arable Crops	Lentils-Dry,Green	Field	Stem, Leave	lentil	stem, leave	1,67	1,67	0,1	0,9	-	-	-	-	-	-	-	1
Arable Crops	Soya Beans	Field	Stem, Leave	soya bean	stem, leave	1,7	1,7	0,5	1	-	-	-	-	-	-	-	1
Arable Crops	Soya Beans	Field	Straw	soya bean	straw	0,75	3,5	0,5	1	-	-	-	-	-	-	-	1
Arable Crops	Groundnuts-In Shell	Field	Straw	groundnut	straw	2,1	2,3	0,15	0,8	-	-	-	-	-	-	-	1
Arable Crops	Seed-Lin	Field	No data	lin		-	-	0,45	0,15	-	-	-	-	-	-	-	0
Arable Crops	Seed-Rape and Colza	Field	Stalk	rape	stalk	1,6	1,8	0,45	0,15	-	-	-	-	-	-	-	1
Arable Crops	Seed-Sesame	Field	Trash	sesame	trash	2	2	0,45	0,15	-	-	-	-	-	-	-	1
Arable Crops	Seed-Sunflower,Oil Production	Field	Stalk	sunflower	stalk	0,6	2,8	0,4	0,6	-	-	-	-	-	-	-	1
Arable Crops	Seed-Safflower Seed	Field	No data	safflower		-	-	0,45	0,15	-	-	-	-	-	-	-	0
Arable Crops	Seed-Hemp	Field	Stem, Leave	hemp	stem, leave	2,5	2,5	0,45	0,15	-	-	-	-	-	-	-	1
Arable Crops	Seed-Poppy	Field	No data	poppy		-	-	0,45	0,15	-	-	-	-	-	-	-	0
Arable Crops	Rice-Not Husked	Field	Straw	rice	straw	0,63	1,76	0,25	0,6	-	-	-	-	-	-	-	1
Arable Crops	Potatoes	Field	Vine	potato	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Potatoes	Field	Tuber	potato	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Potatoes-Sweet	Field	Vine	sweet potato	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Potatoes-Sweet	Field	Tuber	sweet potato	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Other Edible Roots and Tubers-Jerusalem Artichokes	Field	Vine	jerusalem artichoke	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Other Edible Roots and Tubers-Jerusalem Artichokes	Field	Tuber	jerusalem artichoke	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Other Edible Roots and Tubers-Salep	Field	Vine	salep	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1

Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_RPR_min	F_RPR_max	F_MOIST	F_AVAIL	IND_min	IND_max	I_RPR_min	I_RPR_max	I_AVAIL	I_MOIST_min	I_MOIST_max	MC
Arable Crops	Other Edible Roots and Tubers-Salep	Field	Tuber	salep	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Arable Crops	Sugar Beet	Field	Leave	sugar beet	leave	0,12	0,4	0,8	0,5	-	-	-	-	-	-	-	1
Arable Crops	Sugar Beet Seeds	Field	Leave	sugar beet seed	seed	0,12	0,4	0,45	0,15	-	-	-	-	-	-	-	1
Arable Crops	Sugar Cane	Field	Top, Leave	sugar cane	top, leave	0,1	0,3	0,8	0,5	-	-	-	-	-	-	-	1
Arable Crops	Tobacco-Unmanufactured	Field	Stalk, Stem	tobacco	stalk, stem	1,05	2,27	0,85	1	-	-	-	-	-	-	-	1
Horticulture Plants	Beans-Green	Field	No data	bean		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Kidney Beans-Green	Field	No data	bean		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Peas-Green	Field	No data	pea		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Green Leguminous Vegetables-Broad Beans	Field	No data	broad bean		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Green Leguminous Vegetables-Cow Pea	Field	No data	cow pea		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Asparagus	Field	No data	asparagus		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Cabbages-White	Field	Foliage, Stem	cabbage	foliage, stem	2,5	2,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Cabbages-Red	Field	Foliage, Stem	cabbage	foliage, stem	2,5	2,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Cabbages-Black	Field	Foliage, Stem	cabbage	foliage, stem	2,5	2,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Cabbages-Brussels Sprouts	Field	Foliage, Stem	cabbage	foliage, stem	2,5	2,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Cauliflowers	Field	No data	cauliflower		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Broccoli	Field	No data	broccoli		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Lettuce and Chicory-Curly	Field	No data	lettuce		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Lettuce and Chicory-Head	Field	No data	lettuce		-	-	0,85	0,95	-	-	-	-	-	-	-	0

Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_ min	IND_ max	I_RPR _min	I_RPR _max	I_ AVAIL	I MOIST_ min	I_ MOIST_ max	MC
Horticulture Plants	Lettuce and Chicory-Iceberg	Field	No data	lettuce		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Spinach	Field	No data	spinach		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Artichokes	Field	No data	artichoke		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Parsley	Field	No data	parsley		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Rocket	Field	No data	rocket		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Mint	Field	No data	mint		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Dill	Field	No data	dill		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Purslane	Field	No data	purslane		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Cress	Field	No data	cress		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Chards	Field	No data	chard		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Leafy or Stem Vegetables-Celery	Field	No data	celery		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Watermelons	Field	No data	watermelon		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Cantaloupes and Other Melons	Field	No data	melon		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Chilles and Peppers-Paprika	Field	No data	paprika		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Chilles and Peppers-Thin Tapered	Field	No data	pepper		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Chilles and Peppers-Stuffing	Field	No data	pepper		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Chilles and Peppers-Charleston	Field	No data	pepper		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Cucumbers and Gherkins-Cucumber	Field	No data	cucumber		-	-	0,85	0,95	-	-	-	-	-	-	-	0

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Horticulture Plants	Cucumbers and Gherkins-Gherkins	Field	No data	gherkin		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Eggplants	Field	No data	eggplant		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Tomatoes,Product ion	Field	Stem, Leave	tomato	stem, leave	0,3	0,3	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Pumpkins,Squash and Gourds-Squash	Field	No data	squash		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Pumpkins,Squash and Gourds-Pumpkin	Field	No data	pumpkin		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Fruit-Bearing Vegetables-Okra	Field	No data	okra		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Tropical and Subtropical Fruits-Pepino	Field	No data	pepino		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Pumpkins,Squash and Gourds-Bitter Melon	Field	No data	Bitter melon		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Carrots and Turnips-Carrots	Field	Vine	carrot	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Carrots and Turnips-Carrots	Field	Tuber	carrot	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Carrots and Turnips-Turnips	Field	Vine	turnip	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Carrots and Turnips-Turnips	Field	Tuber	turnip	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Garlic-Dry	Field	No data	garlic		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Onions-Dry	Field	No data	onion		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Leeks and Other Alliaceous Vegetables-Leek	Field	No data	leek		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Red Radish	Field	Vine	red radish	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Red Radish	Field	Tuber	red radish	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Celeriac	Field	Vine	celeriac	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1

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Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Celeriac	Field	Tuber	celeriac	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Beetroot	Field	Vine	beetroot	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Beetroot	Field	Tuber	beetroot	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Horseradish	Field	Vine	horseradish	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Horseradish	Field	Tuber	horseradish	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-White Radish	Field	Vine	white radish	vine	0,11	0,45	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-White Radish	Field	Tuber	white radish	tuber	0,5	0,5	0,85	0,95	-	-	-	-	-	-	-	1
Horticulture Plants	Mushrooms and Truffles	Field	No data	mushroom		-	-	0,85	0,95	-	-	-	-	-	-	-	0
Fruit Plants	Grapes-Seedless,for Drying	Field	Prunings	grape	pruning	0,39	0,61	0,5	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Grapes-Wine industry	Field	Prunings	grape	pruning	0,39	0,61	0,5	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Grapes-Seeded,for Drying	Field	Prunings	grape	pruning	0,39	0,61	0,5	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Avocados	Field	No data	avocado		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Bananas and Plantains	Field	Stem, Leave	banana	stem, leave	0,7	0,7	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Figs	Field	Prunings	fig	pruning	0,21	0,45	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Pomelos and Grapefruits	Field	Prunings	grapefruit	pruning	0,11	0,11	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Lemons and Limes	Field	Prunings	lemon	pruning	0,19	0,4	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Oranges-Washington	Field	Prunings	orange	pruning	0,2	2,9	0,4	0,8	-	-	-	-	-	-	-	1

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Fruit Plants	Oranges-Other	Field	Prunings	orange	pruning	0,2	2,9	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Oranges-Navel	Field	Prunings	orange	pruning	0,2	2,9	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Tangarines, mandarins, clementines-Other	Field	Prunings	tangarine	pruning	0,17	1,55	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Tangarines, mandarins, clementines-Satsuma	Field	Prunings	tangarine	pruning	0,17	1,55	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Tangarines, mandarins, clementines-Klemantin	Field	Prunings	tangarine	pruning	0,17	1,55	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Tangarines, mandarins, clementines-King	Field	Prunings	tangarine	pruning	0,17	1,55	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Citrus Fruits	Field	No data	citrus		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Apples-Starking	Field	Prunings	apple	pruning	0,14	0,47	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Apples-Other	Field	Prunings	apple	pruning	0,14	0,47	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Apples-Golden	Field	Prunings	apple	pruning	0,14	0,47	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Apples-Amasya	Field	Prunings	apple	pruning	0,14	0,47	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Apples-Granny Smith	Field	Prunings	apple	pruning	0,14	0,47	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Pears	Field	Prunings	pear	pruning	0,14	0,45	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Quinces	Field	Prunings	quince	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Apricots	Field	Prunings	apricot	pruning	0,18	2,84	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Apricots-Wild	Field	Prunings	apricot	pruning	0,18	2,84	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Cherries	Field	Prunings	cherry	pruning	0,19	1,2	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Sour Cherries	Field	Prunings	sour cherry	pruning	0,19	1,2	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Peaches	Field	Prunings	peach	pruning	0,2	0,5	0,4	0,8	-	-	-	-	-	-	-	1

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Fruit Plants	Nectarines	Field	Prunings	nectarine	pruning	0,3	0,5	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Plums	Field	Prunings	plum	pruning	0,3	0,5	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Loquat	Field	Prunings	loquat	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Pome Fruits and Stone Fruits-Cornelian Cherry	Field	Prunings	cornelian cherry	pruning	0,3	0,5	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Pome Fruits and Stone Fruits-Oleaster	Field	Prunings	oleaster	pruning	0,3	0,5	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Pome Fruits and Stone Fruits-Jujube	Field	Prunings	jujube	pruning	0,3	0,5	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Kiwi Fruit	Field	Prunings	kiwi	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Raspberries	Field	No data	raspberry		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Strawberries	Field	No data	strawberry		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Other Berries-Mulberry	Field	No data	mulberry		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Other Berries-Blackberry	Field	No data	blackberry		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Other Berries-Blueberry	Field	No data	blueberry		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Almonds	Field	Prunings	almond	pruning	0,28	2,74	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Chestnuts	Field	No data	chestnut		-	-	0,4	0,8	-	-	-	-	-	-	-	0
Fruit Plants	Hazelnuts	Field	Prunings	hazelnut	pruning	1,9	1,9	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Pistachios	Field	Prunings	pistachio	pruning	0,4	2,7	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Walnuts	Field	Prunings	walnut	pruning	0,44	0,44	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Tree and Bush Fruits-Pomegranate	Field	Prunings	pomegranate	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Tree and Bush Fruits-Persimmon	Field	Prunings	persimmon	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Other Tree and Bush Fruits-Locust Bean	Field	Prunings	locust bean	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1

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Fruit Plants	Other Tree and Bush Fruits-Medlar	Field	Prunings	medlar	pruning	0,14	0,3	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Olives-Olive Oil	Field	Prunings	olive	pruning	0,05	0,29	0,4	0,8	-	-	-	-	-	-	-	1
Fruit Plants	Tea-Leaves	Field	No data	tea		-	-	0	0	-	-	-	-	-	-	-	0
Arable Crops	Wheat-Durum	Agro-Industry	Husk	wheat	husk	-	-	-	-	1	1	0,15	0,2	0,8	0,05	0,2	1
Arable Crops	Wheat-Durum	Agro-Industry	Bran	wheat	bran	-	-	-	-	1	1	0,13	0,25	0,8	0,05	0,2	1
Arable Crops	Wheat-Other	Agro-Industry	Husk	wheat	husk	-	-	-	-	1	1	0,15	0,2	0,8	0,05	0,2	1
Arable Crops	Wheat-Other	Agro-Industry	Bran	wheat	bran	-	-	-	-	1	1	0,13	0,25	0,8	0,05	0,2	1
Arable Crops	Maize	Agro-Industry	Husk	maize	husk	-	-	-	-	1	1	0,06	0,14	0,8	0,05	0,2	1
Arable Crops	Maize	Agro-Industry	Cob	maize	cob	-	-	-	-	1	1	0,11	0,86	0,8	0,05	0,2	1
Arable Crops	Barley-Other	Agro-Industry	Husk	barley	husk	-	-	-	-	1	1	0,14	0,4	0,8	0,05	0,2	1
Arable Crops	Barley-Other	Agro-Industry	Bran	barley	bran	-	-	-	-	1	1	0,15	0,49	0,8	0,05	0,2	1
Arable Crops	Barley-Beer	Agro-Industry	Bagasse	barley	bagasse	-	-	-	-	1	1	0,2	0,25	0,8	0,05	0,2	1
Arable Crops	Barley-Beer	Agro-Industry	Spent barley grains	barley	grain	-	-	-	-	1	1	0,85	0,85	0,8	0,05	0,2	1
Arable Crops	Rye	Agro-Industry	Husk	rye		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Rye	Agro-Industry	Bran	rye	bran	-	-	-	-	1	1	0,05	0,15	0,8	0,05	0,2	1
Arable Crops	Oats	Agro-Industry	Husk	oat	husk	-	-	-	-	1	1	0,25	0,32	0,8	0,05	0,2	1
Arable Crops	Oats	Agro-Industry	Bran	oat	bran	-	-	-	-	1	1	0,15	0,15	0,8	0,05	0,2	1
Arable Crops	Sorghum	Agro-Industry	Husk,bran	sorghum		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Millet	Agro-Industry	Husk,bran	millet		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0

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Arable Crops	Chick Peas-Dry	Agro-Industry	Discarded seeds, hulls and dark or spotted seeds	chick pea	seed, hull	-	-	-	-	0,35	0,4	0,05	0,25	0,8	0,05	0,2	1
Arable Crops	Lentils-Dry,Red	Agro-Industry	Discarded seeds, hulls and dark or spotted seeds	lentil	seed, hull	-	-	-	-	0,35	0,4	0,05	0,25	0,8	0,05	0,2	1
Arable Crops	Lentils-Dry,Green	Agro-Industry	Discarded seeds, hulls and dark or spotted seeds	lentil	seed, hull	-	-	-	-	0,35	0,4	0,05	0,25	0,8	0,05	0,2	1
Arable Crops	Soya Beans	Agro-Industry	Shell	soya bean	shell	-	-	-	-	1	1	0,08	0,125	0,8	0,05	0,2	1
Arable Crops	Soya Beans	Agro-Industry	Cake	soya bean	cake	-	-	-	-	1	1	0,06	0,06	0,8	0,05	0,2	1
Arable Crops	Groundnuts-In Shell	Agro-Industry	Shell	groundnut	shell	-	-	-	-	1	1	0,2	0,52	0,8	0,05	0,2	1
Arable Crops	Seed-Lin	Agro-Industry	-	lin		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Seed-Rape and Colza	Agro-Industry	-	rape		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Seed-Sesame	Agro-Industry	-	sesame		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Seed-Sunflower,Oil Production	Agro-Industry	Shell	sunflower	shell	-	-	-	-	1	1	0,2	0,2	0,8	0,05	0,2	1
Arable Crops	Seed-Safflower Seed	Agro-Industry	-	safflower		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Seed-Hemp	Agro-Industry	-	hemp		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Seed-Poppy	Agro-Industry	-	poppy		-	-	-	-	1	1	-	-	0,8	0,05	0,2	0
Arable Crops	Rice-Not Husked	Agro-Industry	Husk	rice	husk	-	-	-	-	1	1	0,04	0,36	0,8	0,05	0,2	1
Arable Crops	Rice-Not Husked	Agro-Industry	Bran	rice	bran	-	-	-	-	1	1	0,08	0,12	0,8	0,05	0,2	1
Arable Crops	Potatoes	Agro-Industry	Peel	potato	peel	-	-	-	-	0,08	0,15	0,06	0,2	0,8	0,2	0,75	1
Arable Crops	Potatoes-Sweet	Agro-Industry	Peel	sweet potato	peel	-	-	-	-	0,08	0,15	0,06	0,2	0,8	0,2	0,75	1

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Arable Crops	Other Edible Roots and Tubers-Jerusalem Artichokes	Agro-Industry	Peel	jerusalem artichoke		-	-	-	-	0,08	0,15	-	-	0,8	0,2	0,75	0
Arable Crops	Other Edible Roots and Tubers-Salep	Agro-Industry	Peel	salep		-	-	-	-	1	1	-	-	0,8	0,2	0,75	0
Arable Crops	Sugar Beet	Agro-Industry	Pulp	sugar beet	pulp	-	-	-	-	0,35	0,4	0,05	0,3	0,8	0,75	0,9	1
Arable Crops	Sugar Beet Seeds	Agro-Industry	-	sugar beet seed		-	-	-	-	1	1	-	-	0,8	0,2	0,75	0
Arable Crops	Sugar Cane	Agro-Industry	Pulp	sugar cane	pulp	-	-	-	-	1	1	0,05	0,3	0,8	0,75	0,9	1
Arable Crops	Tobacco-Unmanufactured	Agro-Industry	Solid waste	tobacco	waste	-	-	-	-	1	1	0,2	0,2	0,8	0,05	0,2	1
Horticulture Plants	Beans-Green	Agro-Industry	Shell	bean	shell	-	-	-	-	0,05	0,25	0,6	0,8	0,8	0,2	0,75	1
Horticulture Plants	Kidney Beans-Green	Agro-Industry	Shell	bean	shell	-	-	-	-	0,05	0,25	0,6	0,8	0,8	0,2	0,75	1
Horticulture Plants	Peas-Green	Agro-Industry	Shell	pea	shell	-	-	-	-	0,05	0,25	0,1	0,1	0,8	0,2	0,75	1
Horticulture Plants	Other Green Leguminous Vegetables-Broad Beans	Agro-Industry	Shell	broad bean	shell	-	-	-	-	0,05	0,25	0,1	0,1	0,8	0,2	0,75	1
Horticulture Plants	Other Green Leguminous Vegetables-Cow Pea	Agro-Industry	Shell	cow pea	shell	-	-	-	-	0,05	0,25	0,6	0,8	0,8	0,2	0,75	1
Horticulture Plants	Asparagus	Agro-Industry	Spear	asparagus	spear	-	-	-	-	0,05	0,25	0,4	0,6	0,8	0,2	0,75	1
Horticulture Plants	Cabbages-White	Agro-Industry	Leaves, stem, curd	cabbage	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,5	0,8	0,75	0,9	1
Horticulture Plants	Cabbages-Red	Agro-Industry	Leaves, stem, curd	cabbage	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,5	0,8	0,75	0,9	1
Horticulture Plants	Cabbages-Black	Agro-Industry	Leaves, stem, curd	cabbage	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,5	0,8	0,75	0,9	1
Horticulture Plants	Cabbages-Brussels Sprouts	Agro-Industry	Leaves, stem, curd	cabbage	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,5	0,8	0,75	0,9	1
Horticulture Plants	Cauliflowers	Agro-Industry	Leaves, stem, curd	cauliflower	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,5	0,8	0,75	0,9	1
Horticulture Plants	Broccoli	Agro-Industry	Leaves, stem, curd	broccoli	leave, stem, curd	-	-	-	-	0,05	0,25	0,5	0,75	0,8	0,75	0,9	1
Horticulture Plants	Lettuce and Chicory-Curly	Agro-Industry	Leaves, stem, curd	lettuce	leave, stem, curd	-	-	-	-	0,05	0,25	0,41	0,41	0,8	0,75	0,9	1
Horticulture Plants	Lettuce and Chicory-Head	Agro-Industry	Leaves, stem, curd	lettuce	leave, stem, curd	-	-	-	-	0,05	0,25	0,41	0,41	0,8	0,75	0,9	1

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Horticulture Plants	Lettuce and Chicory-Iceberg	Agro-Industry	Leaves, stem, curd	lettuce	leave, stem, curd	-	-	-	-	0,05	0,25	0,41	0,41	0,8	0,75	0,9	1
Horticulture Plants	Spinach	Agro-Industry	Leaves, stem, curd	spinach	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Artichokes	Agro-Industry	Leaves, stem, curd	artichoke	leave, stem, curd	-	-	-	-	0,05	0,25	0,6	0,7	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Parsley	Agro-Industry	Leaves, stem, curd	parsley	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Rocket	Agro-Industry	Leaves, stem, curd	rocket	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Mint	Agro-Industry	Leaves, stem, curd	mint	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Dill	Agro-Industry	Leaves, stem, curd	dill	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Purslane	Agro-Industry	Leaves, stem, curd	purslane	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Cress	Agro-Industry	Leaves, stem, curd	cress	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Chards	Agro-Industry	Leaves, stem, curd	chard	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Other Leafy or Stem Vegetables-Celery	Agro-Industry	Leaves, stem, curd	celery	leave, stem, curd	-	-	-	-	0,05	0,25	0,3	0,3	0,8	0,75	0,9	1
Horticulture Plants	Watermelons	Agro-Industry	Peel	watermelon	peel	-	-	-	-	0,05	0,25	0,3	0,41	0,8	0,75	0,9	1
Horticulture Plants	Watermelons	Agro-Industry	Seed	watermelon	seed	-	-	-	-	0,05	0,25	0,02	0,02	0,8	0,75	0,9	1
Horticulture Plants	Watermelons	Agro-Industry	Flesh	watermelon	flesh	-	-	-	-	0,05	0,25	0,57	0,68	0,8	0,75	0,9	1
Horticulture Plants	Cantaloupes and Other Melons	Agro-Industry	Peel	melon	peel	-	-	-	-	0,05	0,25	0,25	0,44	0,8	0,75	0,9	1
Horticulture Plants	Cantaloupes and Other Melons	Agro-Industry	Seed	melon	seed	-	-	-	-	0,05	0,25	0,034	0,07	0,8	0,75	0,9	1
Horticulture Plants	Cantaloupes and Other Melons	Agro-Industry	Flesh	melon	flesh	-	-	-	-	0,05	0,25	0,52	0,65	0,8	0,75	0,9	1
Horticulture Plants	Chilles and Peppers-Paprika	Agro-Industry	Peel, seed, placenta, peduncle	paprika	peel, seed	-	-	-	-	0,05	0,25	0,05	0,6	0,8	0,75	0,9	1

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Horticulture Plants	Chilles and Peppers-Thin Tapered	Agro-Industry	Peel, seed, placenta, peduncle	pepper	peel, seed	-	-	-	-	0,05	0,25	0,05	0,6	0,8	0,75	0,9	1
Horticulture Plants	Chilles and Peppers-Stuffing	Agro-Industry	Peel, seed, placenta, peduncle	pepper	peel, seed	-	-	-	-	0,05	0,25	0,05	0,6	0,8	0,75	0,9	1
Horticulture Plants	Chilles and Peppers-Charleston	Agro-Industry	Peel, seed, placenta, peduncle	pepper	peel, seed	-	-	-	-	0,05	0,25	0,05	0,6	0,8	0,75	0,9	1
Horticulture Plants	Cucumbers and Gherkins-Cucumber	Agro-Industry	Peel	cucumber		-	-	-	-	0,96	0,96	-	-	0,8	0,75	0,9	0
Horticulture Plants	Cucumbers and Gherkins-Gherkins	Agro-Industry	Peel	gherkin		-	-	-	-	0,96	0,96	-	-	0,8	0,75	0,9	0
Horticulture Plants	Eggplants	Agro-Industry	Peel	eggplant	peel	-	-	-	-	0,05	0,25	0,143	0,143	0,8	0,75	0,9	1
Horticulture Plants	Eggplants	Agro-Industry	Pulp	eggplant	pulp	-	-	-	-	0,05	0,25	0,041	0,041	0,8	0,75	0,9	1
Horticulture Plants	Tomatoes,Product ion	Agro-Industry	Peel	tomato	peel	-	-	-	-	0,96	0,96	0,03	0,1	0,8	0,75	0,9	1
Horticulture Plants	Tomatoes,Product ion	Agro-Industry	Seed	tomato	seed	-	-	-	-	0,96	0,96	0,06	0,07	0,8	0,75	0,9	1
Horticulture Plants	Tomatoes,Product ion	Agro-Industry	Pulp	tomato	pulp	-	-	-	-	0,96	0,96	0,04	0,2	0,8	0,75	0,9	1
Horticulture Plants	Pumpkins,Squash and Gourds-Squash	Agro-Industry	Peel	squash		-	-	-	-	0,05	0,25	-	-	0,8	0,75	0,9	0
Horticulture Plants	Pumpkins,Squash and Gourds-Pumpkin	Agro-Industry	Peel	pumpkin	peel	-	-	-	-	0,05	0,25	0,026	0,16	0,8	0,75	0,9	1
Horticulture Plants	Pumpkins,Squash and Gourds-Pumpkin	Agro-Industry	Seed	pumpkin	seed	-	-	-	-	0,05	0,25	0,031	0,044	0,8	0,75	0,9	1
Horticulture Plants	Pumpkins,Squash and Gourds-Pumpkin	Agro-Industry	Flesh	pumpkin	flesh	-	-	-	-	0,05	0,25	0,72	0,76	0,8	0,75	0,9	1
Horticulture Plants	Other Fruit-Bearing Vegetables-Okra	Agro-Industry	Head	okra		-	-	-	-	0,05	0,25	-	-	0,8	0,75	0,9	0
Horticulture Plants	Other Tropical and Subtropical Fruits-Pepino	Agro-Industry	Peel, seed, pulp	pepino		-	-	-	-	0,05	0,25	-	-	0,8	0,75	0,9	0
Horticulture Plants	Pumpkins,Squash and Gourds-Bitter Melon	Agro-Industry	Peel	bitter melon	peel	-	-	-	-	0,05	0,25	0,026	0,16	0,8	0,75	0,9	1

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Horticulture Plants	Pumpkins,Squash and Gourds-Bitter Melon	Agro-Industry	Seed	bitter melon	seed	-	-	-	-	0,05	0,25	0,031	0,044	0,8	0,75	0,9	1
Horticulture Plants	Pumpkins,Squash and Gourds-Bitter Melon	Agro-Industry	Pulp	bitter melon	pulp	-	-	-	-	0,05	0,25	0,72	0,76	0,8	0,75	0,9	1
Horticulture Plants	Carrots and Turnips-Carrots	Agro-Industry	Pulp	carrot	pulp	-	-	-	-	0,05	0,25	0,12	0,4	0,8	0,75	0,9	1
Horticulture Plants	Carrots and Turnips-Turnips	Agro-Industry	Pulp	turnip	pulp	-	-	-	-	0,05	0,25	0,12	0,4	0,8	0,75	0,9	1
Horticulture Plants	Garlic-Dry	Agro-Industry	Straw, peel	garlic	straw, peel	-	-	-	-	0,05	0,25	0,13	0,24	0,8	0,2	0,75	1
Horticulture Plants	Onions-Dry	Agro-Industry	Straw, peel	onion	straw, peel	-	-	-	-	0,05	0,25	0,1	0,38	0,8	0,2	0,75	1
Horticulture Plants	Leeks and Other Alliaceous Vegetables-Leek	Agro-Industry	Stem	leek	stem	-	-	-	-	0,05	0,25	0,32	0,6	0,8	0,2	0,75	1
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Red Radish	Agro-Industry	Leaves, peel, pulp	red radish		-	-	-	-	0,05	0,25	-	-	0,8	0,2	0,75	0
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Celeriac	Agro-Industry	Leaves, peel, pulp	celeriac		-	-	-	-	0,05	0,25	-	-	0,8	0,75	0,9	0
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Beetroot	Agro-Industry	Leaves, peel, pulp	beetroot		-	-	-	-	0,05	0,25	-	-	0,8	0,75	0,9	0
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-Horseradish	Agro-Industry	Leaves, peel, pulp	horseradish		-	-	-	-	0,05	0,25	-	-	0,8	0,2	0,75	0
Horticulture Plants	Other Root, Bulb or Tuberous Vegetables-White Radish	Agro-Industry	Leaves, peel, pulp	White radish		-	-	-	-	0,05	0,25	-	-	0,8	0,2	0,75	0
Horticulture Plants	Mushrooms and Truffles	Agro-Industry	-	mushroom		-	-	-	-	0,05	0,25	-	-	0,8	0,2	0,75	0
Fruit Plants	Grapes-Seedless,for Drying	Agro-Industry	Stalk	grape	stalk	-	-	-	-	1	1	0,025	0,075	0,8	0,2	0,75	1
Fruit Plants	Grapes-Wine industry	Agro-Industry	Stalk	grape	stalk	-	-	-	-	1	1	0,025	0,075	0,8	0,75	0,9	1
Fruit Plants	Grapes-Wine industry	Agro-Industry	Peel	grape	peel	-	-	-	-	1	1	0,165	0,2	0,8	0,75	0,9	1
Fruit Plants	Grapes-Wine industry	Agro-Industry	Seed	grape	seed	-	-	-	-	1	1	0,03	0,13	0,8	0,75	0,9	1
Fruit Plants	Grapes-Wine industry	Agro-Industry	Pulp	grape	pulp	-	-	-	-	1	1	0,13	0,45	0,8	0,75	0,9	1

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Fruit Plants	Grapes-Seeded,for Drying	Agro-Industry	Stalk	grape	stalk	-	-	-	-	1	1	0,025	0,075	0,8	0,2	0,75	1
Fruit Plants	Avocados	Agro-Industry	Peel	avocado	peel	-	-	-	-	0,09	0,2	0,11	0,17	0,8	0,75	0,9	1
Fruit Plants	Avocados	Agro-Industry	Seed	avocado	seed	-	-	-	-	0,09	0,2	0,13	0,2	0,8	0,75	0,9	1
Fruit Plants	Avocados	Agro-Industry	Pulp	avocado	pulp	-	-	-	-	0,09	0,2	0,65	0,73	0,8	0,75	0,9	1
Fruit Plants	Bananas and Plantains	Agro-Industry	Peel	banana	peel	-	-	-	-	0,09	0,2	0,35	0,4	0,8	0,75	0,9	1
Fruit Plants	Bananas and Plantains	Agro-Industry	Seed	banana		-	-	-	-	0,09	0,2	-	-	0,8	0,75	0,9	0
Fruit Plants	Bananas and Plantains	Agro-Industry	Pulp	banana		-	-	-	-	0,09	0,2	-	-	0,8	0,75	0,9	0
Fruit Plants	Figs	Agro-Industry	Peel	fig		-	-	-	-	0,09	0,2	-	-	0,8	0,2	0,75	0
Fruit Plants	Pomelos and Grapefruits	Agro-Industry	Peel	grapefruit	peel	-	-	-	-	0,04	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Pomelos and Grapefruits	Agro-Industry	Seed	grapefruit	seed	-	-	-	-	0,04	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Pomelos and Grapefruits	Agro-Industry	Pulp and rag	grapefruit	pulp	-	-	-	-	0,04	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Lemons and Limes	Agro-Industry	Peel	lemon	peel	-	-	-	-	0,09	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Lemons and Limes	Agro-Industry	Seed	lemon	seed	-	-	-	-	0,09	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Lemons and Limes	Agro-Industry	Pulp and rag	lemon	pulp	-	-	-	-	0,09	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Oranges-Washington	Agro-Industry	Peel	orange	peel	-	-	-	-	0,07	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Oranges-Washington	Agro-Industry	Seed	orange	seed	-	-	-	-	0,07	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Oranges-Washington	Agro-Industry	Pulp and rag	orange	pulp	-	-	-	-	0,07	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Oranges-Other	Agro-Industry	Peel	orange	peel	-	-	-	-	0,07	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Oranges-Other	Agro-Industry	Seed	orange	seed	-	-	-	-	0,07	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Oranges-Other	Agro-Industry	Pulp and rag	orange	pulp	-	-	-	-	0,07	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Oranges-Navel	Agro-Industry	Peel	orange	peel	-	-	-	-	0,07	0,2	0,3	0,3	0,8	0,75	0,9	1

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Fruit Plants	Oranges-Navel	Agro-Industry	Seed	orange	seed	-	-	-	-	0,07	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Oranges-Navel	Agro-Industry	Pulp and rag	orange	pulp	-	-	-	-	0,07	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Other	Agro-Industry	Peel	tangarine	peel	-	-	-	-	0	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Other	Agro-Industry	Seed	tangarine	seed	-	-	-	-	0	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Other	Agro-Industry	Pulp and rag	tangarine	pulp	-	-	-	-	0	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Satsuma	Agro-Industry	Peel	tangarine	peel	-	-	-	-	0	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Satsuma	Agro-Industry	Seed	tangarine	seed	-	-	-	-	0	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Satsuma	Agro-Industry	Pulp and rag	tangarine	pulp	-	-	-	-	0	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Klemantin	Agro-Industry	Peel	tangarine	peel	-	-	-	-	0	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Klemantin	Agro-Industry	Seed	tangarine	seed	-	-	-	-	0	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-Klemantin	Agro-Industry	Pulp and rag	tangarine	pulp	-	-	-	-	0	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-King	Agro-Industry	Peel	tangarine	peel	-	-	-	-	0	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-King	Agro-Industry	Seed	tangarine	seed	-	-	-	-	0	0,2	0,2	0,2	0,8	0,75	0,9	1
Fruit Plants	Tangarines, mandarins, clementines-King	Agro-Industry	Pulp and rag	tangarine	pulp	-	-	-	-	0	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Other Citrus Fruits	Agro-Industry	Peel	citrus	peel	-	-	-	-	0,09	0,2	0,3	0,3	0,8	0,75	0,9	1
Fruit Plants	Other Citrus Fruits	Agro-Industry	Seed	citrus	seed	-	-	-	-	0,09	0,2	0,2	0,2	0,8	0,75	0,9	1

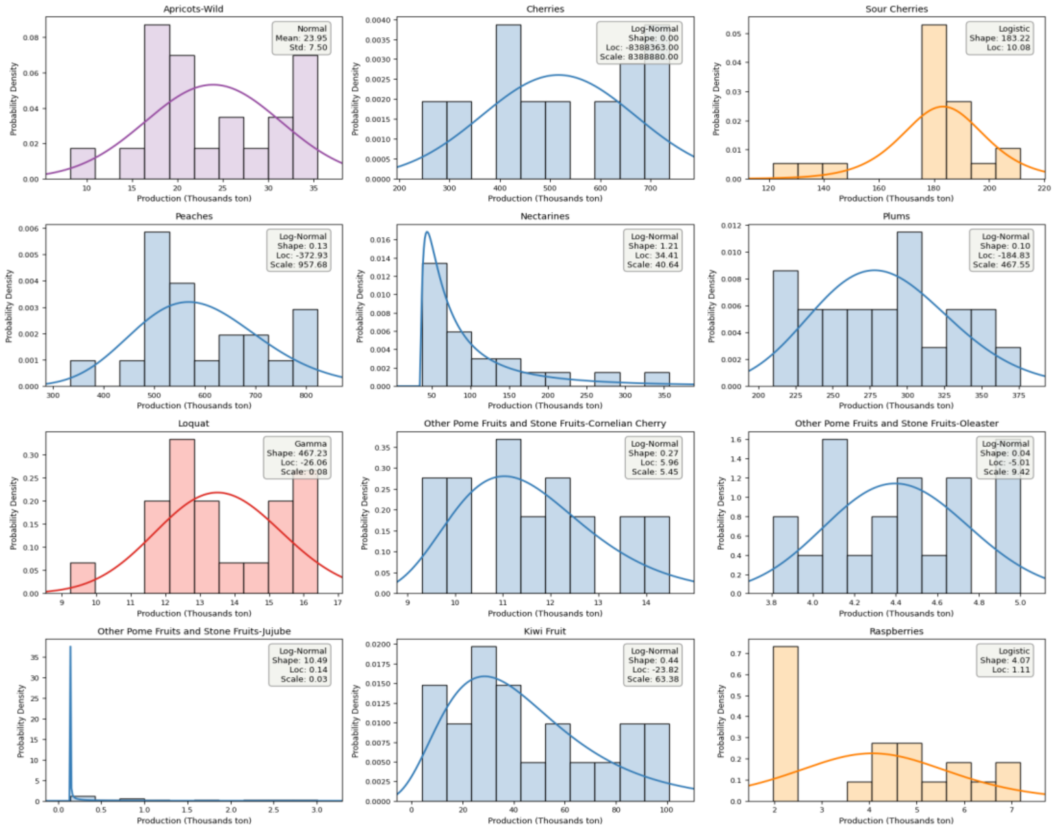
Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_ min	IND_ max	I_RPR _min	I_RPR _max	I_ AVAIL	I MOIST_ min	I_ MOIST_ max	MC
Fruit Plants	Other Citrus Fruits	Agro-Industry	Pulp and rag	citrus	pulp	-	-	-	-	0,09	0,2	0,5	0,7	0,8	0,75	0,9	1
Fruit Plants	Apples-Starking	Agro-Industry	Peel	apple	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Apples-Starking	Agro-Industry	Seed	apple	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1
Fruit Plants	Apples-Starking	Agro-Industry	Pulp	apple	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Apples-Other	Agro-Industry	Peel	apple	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Apples-Other	Agro-Industry	Seed	apple	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1
Fruit Plants	Apples-Other	Agro-Industry	Pulp	apple	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Apples-Golden	Agro-Industry	Peel	apple	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Apples-Golden	Agro-Industry	Seed	apple	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1
Fruit Plants	Apples-Golden	Agro-Industry	Pulp	apple	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Apples-Amasya	Agro-Industry	Peel	apple	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Apples-Amasya	Agro-Industry	Seed	apple	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1
Fruit Plants	Apples-Amasya	Agro-Industry	Pulp	apple	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Apples-Granny Smith	Agro-Industry	Peel	apple	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Apples-Granny Smith	Agro-Industry	Seed	apple	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1
Fruit Plants	Apples-Granny Smith	Agro-Industry	Pulp	apple	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Pears	Agro-Industry	Peel	pear	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Pears	Agro-Industry	Seed	pear	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1
Fruit Plants	Pears	Agro-Industry	Pulp	pear	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Quinces	Agro-Industry	Peel	quince	peel	-	-	-	-	0,09	0,2	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Quinces	Agro-Industry	Seed	quince	seed	-	-	-	-	0,09	0,2	0,02	0,04	0,8	0,75	0,9	1

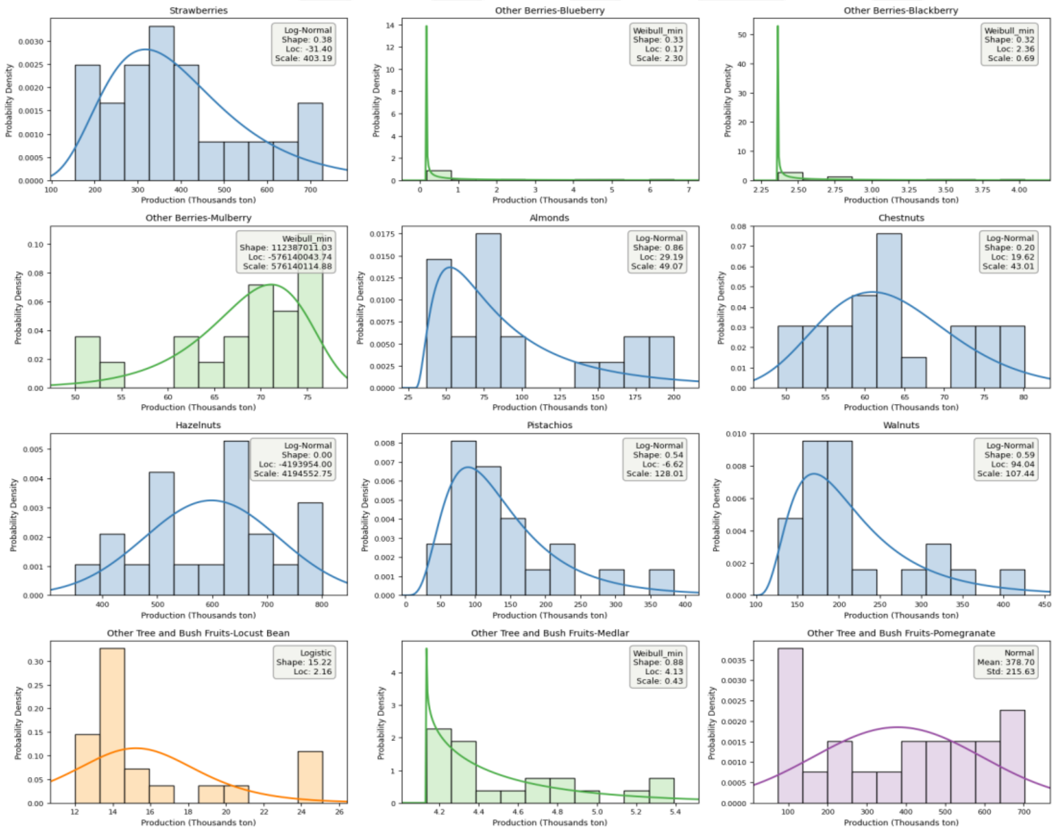
Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_ min	IND_ max	I_RPR _min	I_RPR _max	I_ AVAIL	I_ MOIST_ min	I_ MOIST_ max	MC
Fruit Plants	Quinces	Agro-Industry	Pulp	quince	pulp	-	-	-	-	0,09	0,2	0,2	0,35	0,8	0,75	0,9	1
Fruit Plants	Apricots	Agro-Industry	Peel	apricot	peel	-	-	-	-	0,09	0,3	0,085	0,085	0,8	0,75	0,9	1
Fruit Plants	Apricots	Agro-Industry	Seed	apricot	seed	-	-	-	-	0,09	0,3	0,17	0,33	0,8	0,75	0,9	1
Fruit Plants	Apricots	Agro-Industry	Pulp	apricot	pulp	-	-	-	-	0,09	0,3	0,1	0,1	0,8	0,75	0,9	1
Fruit Plants	Apricots-Wild	Agro-Industry	Peel	apricot	peel	-	-	-	-	0,09	0,3	0,085	0,085	0,8	0,75	0,9	1
Fruit Plants	Apricots-Wild	Agro-Industry	Seed	apricot	seed	-	-	-	-	0,09	0,3	0,17	0,33	0,8	0,75	0,9	1
Fruit Plants	Apricots-Wild	Agro-Industry	Pulp	apricot	pulp	-	-	-	-	0,09	0,3	0,1	0,1	0,8	0,75	0,9	1
Fruit Plants	Cherries	Agro-Industry	Peel	cherry		-	-	-	-	0,09	0,3	-	-	0,8	0,75	0,9	0
Fruit Plants	Cherries	Agro-Industry	Seed	cherry	seed	-	-	-	-	0,09	0,3	0,07	0,35	0,8	0,75	0,9	1
Fruit Plants	Cherries	Agro-Industry	Pulp	cherry	pulp	-	-	-	-	0,09	0,3	0,15	0,28	0,8	0,75	0,9	1
Fruit Plants	Sour Cherries	Agro-Industry	Peel	sour cherry		-	-	-	-	0,09	0,3	-	-	0,8	0,75	0,9	0
Fruit Plants	Sour Cherries	Agro-Industry	Seed	sour cherry	seed	-	-	-	-	0,09	0,3	0,07	0,35	0,8	0,75	0,9	1
Fruit Plants	Sour Cherries	Agro-Industry	Pulp	sour cherry	pulp	-	-	-	-	0,09	0,3	0,15	0,28	0,8	0,75	0,9	1
Fruit Plants	Peaches	Agro-Industry	Peel	peach	peel	-	-	-	-	0,09	0,3	0,04	0,11	0,8	0,75	0,9	1
Fruit Plants	Peaches	Agro-Industry	Seed	peach	seed	-	-	-	-	0,09	0,3	0,11	0,17	0,8	0,75	0,9	1
Fruit Plants	Peaches	Agro-Industry	Pulp	peach	pulp	-	-	-	-	0,09	0,3	0,33	0,33	0,8	0,75	0,9	1
Fruit Plants	Nectarines	Agro-Industry	Peel	nectarine	peel	-	-	-	-	0,09	0,3	0,04	0,11	0,8	0,75	0,9	1
Fruit Plants	Nectarines	Agro-Industry	Seed	nectarine	seed	-	-	-	-	0,09	0,3	0,11	0,17	0,8	0,75	0,9	1
Fruit Plants	Nectarines	Agro-Industry	Pulp	nectarine	pulp	-	-	-	-	0,09	0,3	0,33	0,33	0,8	0,75	0,9	1
Fruit Plants	Plums	Agro-Industry	Peel	plum	peel	-	-	-	-	0,09	0,3	0,04	0,11	0,8	0,75	0,9	1
Fruit Plants	Plums	Agro-Industry	Seed	plum	seed	-	-	-	-	0,09	0,3	0,11	0,17	0,8	0,75	0,9	1

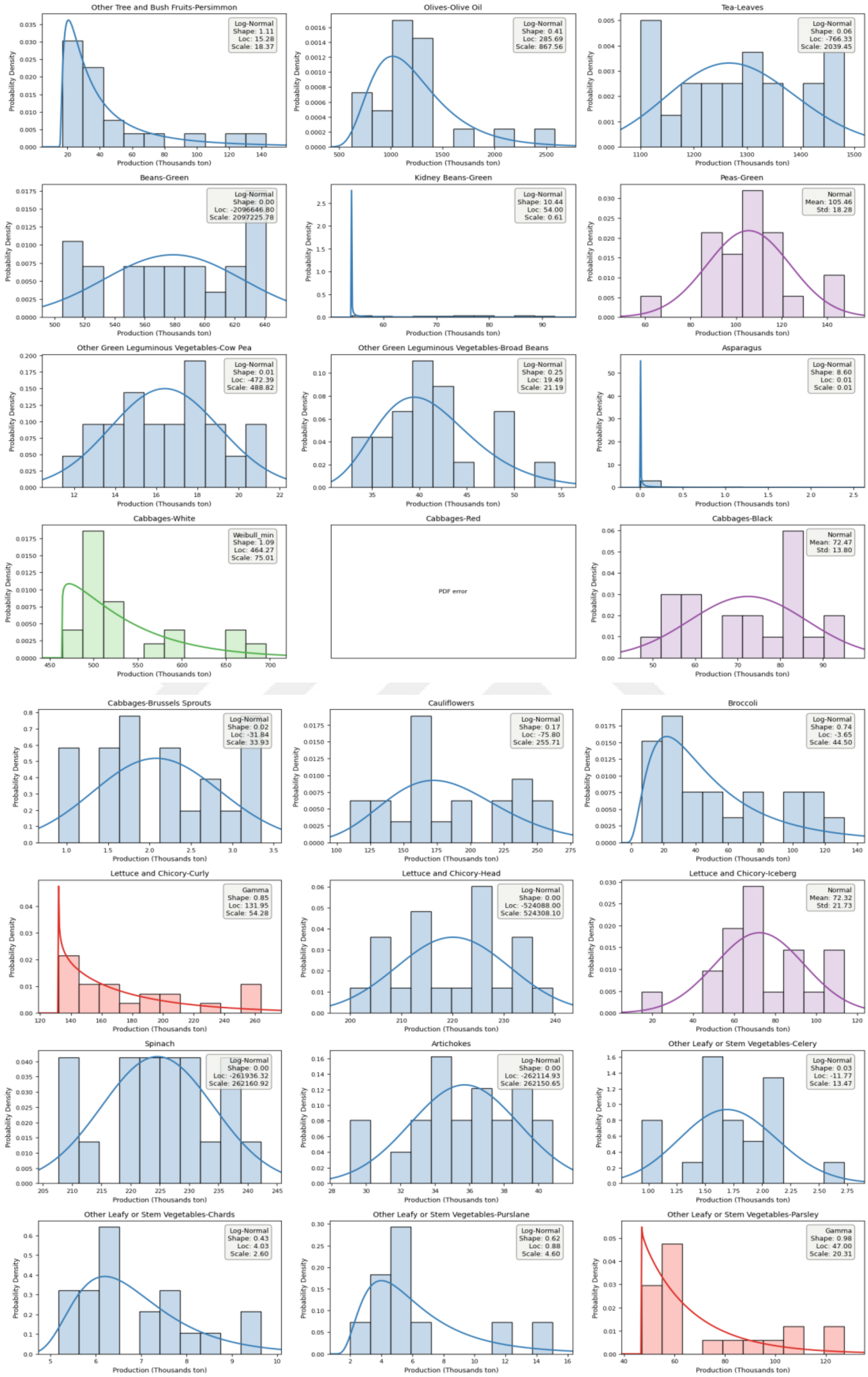
Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_ min	IND_ max	I_RPR _min	I_RPR _max	I_ AVAIL	I MOIST_ min	I_ MOIST_ max	MC
Fruit Plants	Plums	Agro-Industry	Pulp	plum	pulp	-	-	-	-	0,09	0,3	0,25	0,25	0,8	0,75	0,9	1
Fruit Plants	Loquat	Agro-Industry	Peel	loquat	peel	-	-	-	-	0,09	0,3	0,04	0,11	0,8	0,75	0,9	1
Fruit Plants	Loquat	Agro-Industry	Seed	loquat	seed	-	-	-	-	0,09	0,3	0,11	0,3	0,8	0,75	0,9	1
Fruit Plants	Loquat	Agro-Industry	Pulp	loquat	pulp	-	-	-	-	0,09	0,3	0,25	0,25	0,8	0,75	0,9	1
Fruit Plants	Other Pome Fruits and Stone Fruits-Cornelian Cherry	Agro-Industry	Peel	cornelian cherry	Peel	-	-	-	-	0,09	0,3	-	-	0,8	0,75	0,9	0
Fruit Plants	Other Pome Fruits and Stone Fruits-Cornelian Cherry	Agro-Industry	Seed	cornelian cherry	seed	-	-	-	-	0,09	0,3	-	-	0,8	0,75	0,9	0
Fruit Plants	Other Pome Fruits and Stone Fruits-Cornelian Cherry	Agro-Industry	Pulp	cornelian cherry	pulp	-	-	-	-	0,09	0,3	0,05	0,05	0,8	0,75	0,9	1
Fruit Plants	Other Pome Fruits and Stone Fruits-Oleaster	Agro-Industry	Peel	oleaster		-	-	-	-	0,09	0,3	-	-	0,8	0,2	0,75	0
Fruit Plants	Other Pome Fruits and Stone Fruits-Oleaster	Agro-Industry	Seed	oleaster		-	-	-	-	0,09	0,3	-	-	0,8	0,2	0,75	0
Fruit Plants	Other Pome Fruits and Stone Fruits-Oleaster	Agro-Industry	Pulp	oleaster	pulp	-	-	-	-	0,09	0,3	0,05	0,05	0,8	0,2	0,75	1
Fruit Plants	Other Pome Fruits and Stone Fruits-Jujube	Agro-Industry	Peel	jujube		-	-	-	-	0,09	0,3	-	-	0,8	0,2	0,75	0
Fruit Plants	Other Pome Fruits and Stone Fruits-Jujube	Agro-Industry	Seed	jujube		-	-	-	-	0,09	0,3	-	-	0,8	0,2	0,75	0
Fruit Plants	Other Pome Fruits and Stone Fruits-Jujube	Agro-Industry	Pulp	jujube	pulp	-	-	-	-	0,09	0,3	0,05	0,05	0,8	0,2	0,75	1
Fruit Plants	Kiwi Fruit	Agro-Industry	Peel	kiwi	peel	-	-	-	-	0,09	0,2	0,1	0,2	0,8	0,75	0,9	1
Fruit Plants	Kiwi Fruit	Agro-Industry	Seed	kiwi		-	-	-	-	0,09	0,2	-	-	0,8	0,75	0,9	0
Fruit Plants	Kiwi Fruit	Agro-Industry	Pulp	kiwi	pulp	-	-	-	-	0,09	0,2	0,2	0,4	0,8	0,75	0,9	1
Fruit Plants	Raspberries	Agro-Industry	Pulp	raspberry	pulp	-	-	-	-	0,09	0,2	0,2	0,3	0,8	0,75	0,9	1
Fruit Plants	Strawberries	Agro-Industry	Pulp	strawberry	pulp	-	-	-	-	0,09	0,2	0,2	0,3	0,8	0,75	0,9	1
Fruit Plants	Other Berries-Mulberry	Agro-Industry	Pulp	mulberry	pulp	-	-	-	-	0,09	0,2	0,2	0,3	0,8	0,75	0,9	1

Product Class	Product Name	Residue Source	Residue Type	Product Name [Base]	Residue Type [Base]	F_ RPR_ min	F_ RPR_ max	F_ MOIST	F_ AVAIL	IND_ min	IND_ max	I_RPR _min	I_RPR _max	I_ AVAIL	I_ MOIST_ min	I_ MOIST_ max	MC
Fruit Plants	Other Berries-Blackberry	Agro-Industry	Pulp	blackberry	pulp	-	-	-	-	0,09	0,2	0,2	0,3	0,8	0,75	0,9	1
Fruit Plants	Other Berries-Blueberry	Agro-Industry	Pulp	blueberry	pulp	-	-	-	-	0,09	0,2	0,2	0,3	0,8	0,75	0,9	1
Fruit Plants	Almonds	Agro-Industry	Shell	almond	shell	-	-	-	-	1	1	0,43	0,95	0,8	0,05	0,2	1
Fruit Plants	Chestnuts	Agro-Industry	Shell	chestnut	shell	-	-	-	-	0,3	0,3	0,13	0,2	0,8	0,05	0,2	1
Fruit Plants	Hazelnuts	Agro-Industry	Shell	hazelnut	shell	-	-	-	-	0,95	1	0,3	0,88	0,8	0,05	0,2	1
Fruit Plants	Pistachios	Agro-Industry	Shell	pistachio	shell	-	-	-	-	1	1	0,33	0,6	0,8	0,05	0,2	1
Fruit Plants	Walnuts	Agro-Industry	Shell	walnut	shell	-	-	-	-	0,3	0,3	0,45	1,5	0,8	0,05	0,2	1
Fruit Plants	Other Tree and Bush Fruits-Pomegranate	Agro-Industry	Peel	pomegranate	peel	-	-	-	-	0,09	0,2	0,4	0,5	0,8	0,75	0,9	1
Fruit Plants	Other Tree and Bush Fruits-Pomegranate	Agro-Industry	Seed	pomegranate	seed	-	-	-	-	0,09	0,2	0,1	0,1	0,8	0,75	0,9	1
Fruit Plants	Other Tree and Bush Fruits-Persimmon	Agro-Industry	Peel	persimmon		-	-	-	-	0,09	0,2	-	-	0,8	0,75	0,9	0
Fruit Plants	Other Tree and Bush Fruits-Persimmon	Agro-Industry	Seed	persimmon	seed	-	-	-	-	0,09	0,2	0,1	0,15	0,8	0,75	0,9	1
Fruit Plants	Other Tree and Bush Fruits-Persimmon	Agro-Industry	Pulp	persimmon	pulp	-	-	-	-	0,09	0,2	0,27	0,27	0,8	0,75	0,9	1
Fruit Plants	Other Tree and Bush Fruits-Locust Bean	Agro-Industry	Seed	locust bean	sees	-	-	-	-	0,09	0,2	0,1	0,1	0,8	0,2	0,75	1
Fruit Plants	Other Tree and Bush Fruits-Locust Bean	Agro-Industry	Pulp	locust bean	pulp	-	-	-	-	0,09	0,2	0,9	0,9	0,8	0,2	0,75	1
Fruit Plants	Other Tree and Bush Fruits-Medlar	Agro-Industry	Peel	medlar	peel	-	-	-	-	0,09	0,2	0,08	0,08	0,8	0,2	0,75	1
Fruit Plants	Other Tree and Bush Fruits-Medlar	Agro-Industry	Seed	medlar	seed	-	-	-	-	0,09	0,2	0,02	0,08	0,8	0,2	0,75	1
Fruit Plants	Other Tree and Bush Fruits-Medlar	Agro-Industry	Pulp	medlar	pulp	-	-	-	-	0,09	0,2	0,84	0,84	0,8	0,2	0,75	1
Fruit Plants	Olives-Olive Oil	Agro-Industry	Peel	olive	peel	-	-	-	-	1	1	0,15	0,15	0,8	0,2	0,75	1
Fruit Plants	Olives-Olive Oil	Agro-Industry	Seed	olive	seed	-	-	-	-	1	1	0,12	0,5	0,8	0,2	0,75	1
Fruit Plants	Olives-Olive Oil	Agro-Industry	Pulp	olive	pulp	-	-	-	-	1	1	0,3	0,6	0,8	0,2	0,75	1
Fruit Plants	Tea-Leaves	Agro-Industry	Pulp	tea	pulp	-	-	-	-	1	1	0,17	0,17	0,8	0,2	0,75	1

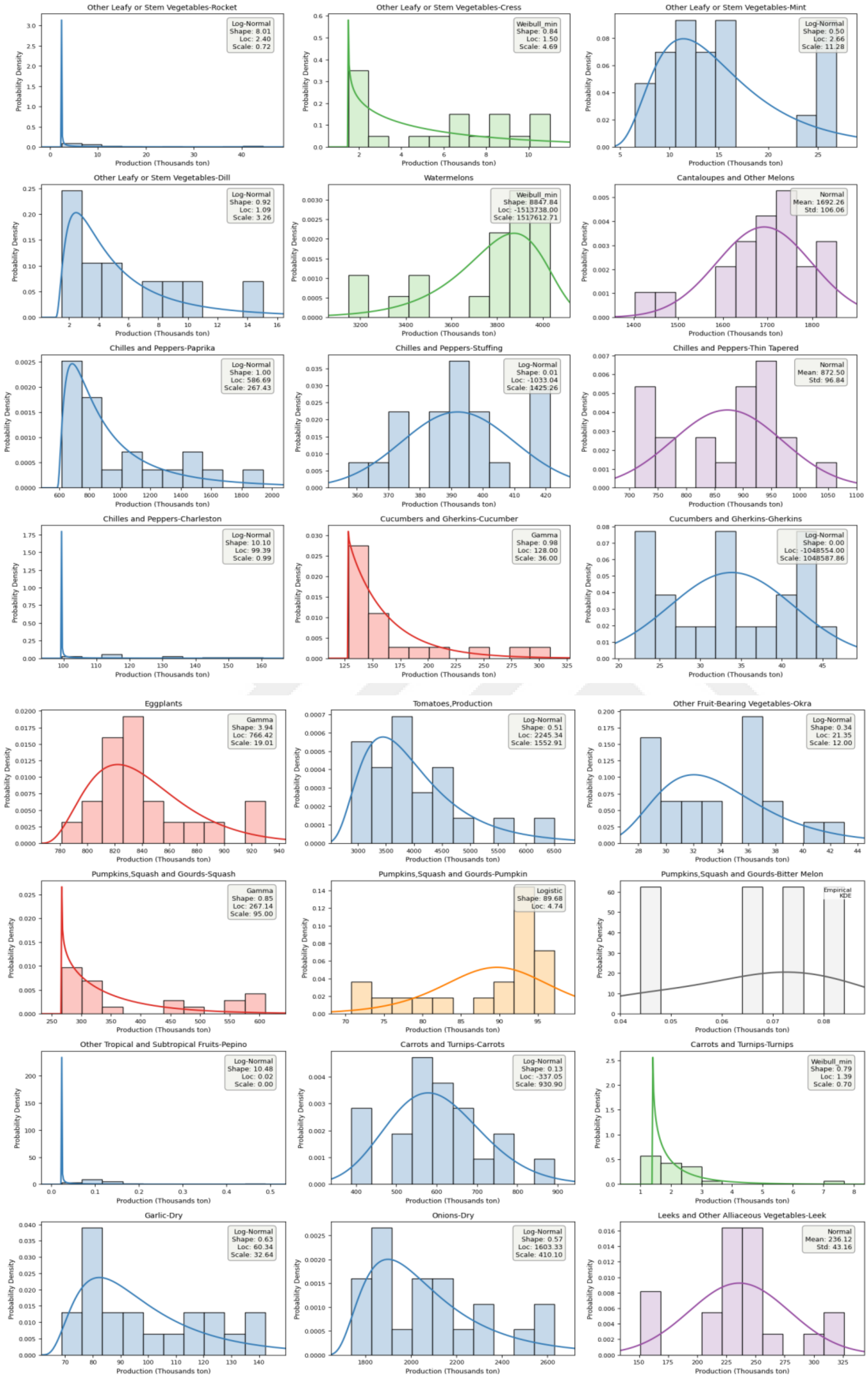
B. DISTRIBUTION PLOTS OF AGRICULTURAL PRODUCTION DATA


Apricots-Wild
Normal Mean: 23.95 Std: 7.50
Cherries
Log-Normal Shape: 0.00 Loc: -8388363.00 Scale: 8388880.00
Sour Cherries
Logistic Shape: 183.22 Loc: 10.08
Peaches
Log-Normal Shape: 0.13 Loc: -372.93 Scale: 957.68
Nectarines
Log-Normal Shape: 1.21 Loc: 34.41 Scale: 40.64
Plums
Log-Normal Shape: 0.10 Loc: -184.83 Scale: 467.55
Loquat
Gamma Shape: 467.23 Loc: -26.06 Scale: 0.08
Other Pome Fruits and Stone Fruits-Cornelian Cherry
Log-Normal Shape: 0.27 Loc: 5.96 Scale: 5.45
Other Pome Fruits and Stone Fruits-Oleaster
Log-Normal Shape: 0.04 Loc: -5.01 Scale: 9.42
Other Pome Fruits and Stone Fruits-Jujube
Log-Normal Shape: 10.49 Loc: 0.14 Scale: 0.03
Kiwi Fruit
Log-Normal Shape: 0.44 Loc: -23.82 Scale: 63.38
Raspberries
Logistic Shape: 4.07 Loc: 1.11
Probability Density
Production (Thousands ton)

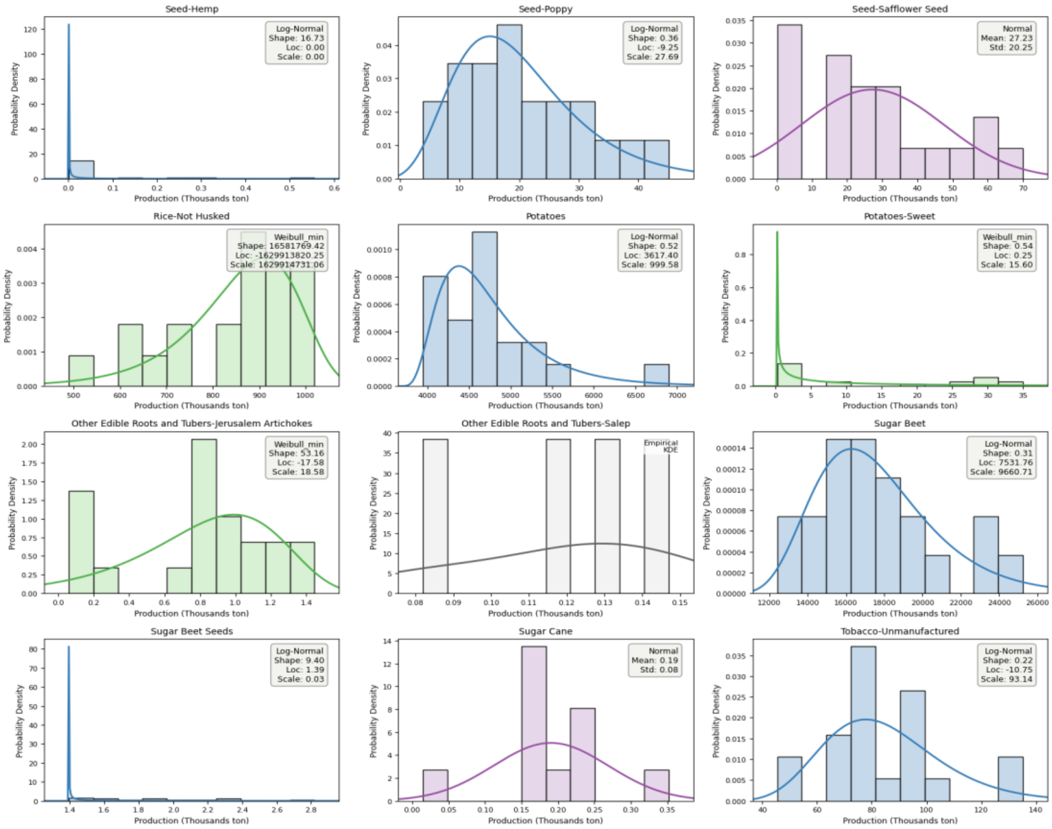

Strawberries
Log-Normal Shape: 0.38 Loc: -31.40 Scale: 403.19
Other Berries-Blueberry
Weibull_min Shape: 0.33 Loc: 0.17 Scale: 2.30
Other Berries-Blackberry
Weibull_min Shape: 0.32 Loc: 2.36 Scale: 0.69
Other Berries-Mulberry
Weibull_min Shape: 112387011.03 Loc: -576140043.74 Scale: 576140114.88
Almonds
Log-Normal Shape: 0.86 Loc: 29.19 Scale: 49.07
Chestnuts
Log-Normal Shape: 0.20 Loc: 19.62 Scale: 43.01
Hazelnuts
Log-Normal Shape: 0.00 Loc: -4193954.00 Scale: 4194552.75
Pistachios
Log-Normal Shape: 0.54 Loc: -6.62 Scale: 128.01
Walnuts
Log-Normal Shape: 0.59 Loc: 94.04 Scale: 107.44
Other Tree and Bush Fruits-Locust Bean
Logistic Shape: 15.22 Loc: 2.16
Other Tree and Bush Fruits-Medlar
Weibull_min Shape: 0.88 Loc: 4.13 Scale: 0.43
Other Tree and Bush Fruits-Pomegranate
Normal Mean: 378.70 Std: 215.63
Probability Density
Production (Thousands ton)



Other Tree and Bush Fruits-Persimmon
Log-Normal Shape: 1.11 Loc: 15.28 Scale: 18.37
Olives-Olive Oil
Log-Normal Shape: 0.41 Loc: 285.69 Scale: 867.56
Tea-Leaves
Log-Normal Shape: 0.06 Loc: -766.33 Scale: 2039.45
Beans-Green
Log-Normal Shape: 0.00 Loc: -2096646.80 Scale: 2097225.78
Kidney Beans-Green
Log-Normal Shape: 10.44 Loc: 54.00 Scale: 0.61
Peas-Green
Normal Mean: 105.46 Std: 18.28
Other Green Leguminous Vegetables-Cow Pea
Log-Normal Shape: 0.01 Loc: -472.39 Scale: 488.82
Other Green Leguminous Vegetables-Broad Beans
Log-Normal Shape: 0.25 Loc: 19.49 Scale: 21.19
Asparagus
Log-Normal Shape: 8.60 Loc: 0.01 Scale: 0.01
Cabbages-White
Weibull_min Shape: 1.09 Loc: 464.27 Scale: 75.01
Cabbages-Red
PDF error
Cabbages-Black
Normal Mean: 72.47 Std: 13.80
Cabbages-Brussels Sprouts
Log-Normal Shape: 0.02 Loc: -31.84 Scale: 33.93
Cauliflowers
Log-Normal Shape: 0.17 Loc: -75.80 Scale: 255.71
Broccoli
Log-Normal Shape: 0.74 Loc: -3.65 Scale: 44.50
Lettuce and Chicory-Curly
Gamma Shape: 0.85 Loc: 131.95 Scale: 54.28
Lettuce and Chicory-Head
Log-Normal Shape: 0.00 Loc: -524088.00 Scale: 524308.10
Lettuce and Chicory-Iceberg
Normal Mean: 72.32 Std: 21.73
Spinach
Log-Normal Shape: 0.00 Loc: -261936.32 Scale: 262160.92
Artichokes
Log-Normal Shape: 0.00 Loc: -262114.93 Scale: 262150.65
Other Leafy or Stem Vegetables-Celery
Log-Normal Shape: 0.03 Loc: -11.77 Scale: 13.47
Other Leafy or Stem Vegetables-Chards
Log-Normal Shape: 0.43 Loc: 4.03 Scale: 2.60
Other Leafy or Stem Vegetables-Purslane
Log-Normal Shape: 0.62 Loc: 0.88 Scale: 4.60
Other Leafy or Stem Vegetables-Parsley
Gamma Shape: 0.98 Loc: 47.00 Scale: 20.31
Probability Density
Production (Thousands ton)


Other Leafy or Stem Vegetables-Rocket
Log-Normal Shape: 8.01 Loc: 2.40 Scale: 0.72
Other Leafy or Stem Vegetables-Cress
Weibull_min Shape: 0.84 Loc: 1.50 Scale: 4.69
Other Leafy or Stem Vegetables-Mint
Log-Normal Shape: 0.50 Loc: 2.66 Scale: 11.28
Other Leafy or Stem Vegetables-Dill
Log-Normal Shape: 0.92 Loc: 1.09 Scale: 3.26
Watermelons
Weibull_min Shape: 8847.84 Loc: -1513738.00 Scale: 1517612.71
Cantaloupes and Other Melons
Normal Mean: 1692.26 Std: 106.06
Chilles and Peppers-Paprika
Log-Normal Shape: 1.00 Loc: 586.69 Scale: 267.43
Chilles and Peppers-Stuffing
Log-Normal Shape: 0.01 Loc: -1033.04 Scale: 1425.26
Chilles and Peppers-Thin Tapered
Normal Mean: 872.50 Std: 96.84
Chilles and Peppers-Charleston
Log-Normal Shape: 10.10 Loc: 99.39 Scale: 0.99
Cucumbers and Gherkins-Cucumber
Gamma Shape: 0.98 Loc: 128.00 Scale: 36.00
Cucumbers and Gherkins-Gherkins
Log-Normal Shape: 0.00 Loc: -1048554.00 Scale: 1048587.86
Eggplants
Gamma Shape: 3.94 Loc: 766.42 Scale: 19.01
Tomatoes,Production
Log-Normal Shape: 0.51 Loc: 2245.34 Scale: 1552.91
Other Fruit-Bearing Vegetables-Okra
Log-Normal Shape: 0.34 Loc: 21.35 Scale: 12.00
Pumpkins,Squash and Gourds-Squash
Gamma Shape: 0.85 Loc: 267.14 Scale: 95.00
Pumpkins,Squash and Gourds-Pumpkin
Logistic Shape: 89.68 Loc: 4.74
Pumpkins,Squash and Gourds-Bitter Melon
Empirical KDE
Other Tropical and Subtropical Fruits-Pepino
Log-Normal Shape: 10.48 Loc: 0.02 Scale: 0.00
Carrots and Turnips-Carrots
Log-Normal Shape: 0.13 Loc: -337.05 Scale: 930.90
Carrots and Turnips-Turnips
Weibull_min Shape: 0.79 Loc: 1.39 Scale: 0.70
Garlic-Dry
Log-Normal Shape: 0.63 Loc: 60.34 Scale: 32.64
Onions-Dry
Log-Normal Shape: 0.57 Loc: 1603.33 Scale: 410.10
Leeks and Other Alliaceous Vegetables-Leek
Normal Mean: 236.12 Std: 43.16
Probability Density
Production (Thousands ton)


Other Root, Bulb or Tuberous Vegetables-Beetroot
Logistic Shape: 8.73 Loc: 2.41
Other Root, Bulb or Tuberous Vegetables-Celeriac
Weibull_min Shape: 0.44 Loc: 14.66 Scale: 4.82
Other Root, Bulb or Tuberous Vegetables-Horseradish
Log-Normal Shape: 0.59 Loc: 11.93 Scale: 3.52
Other Root, Bulb or Tuberous Vegetables-Red Radish
Log-Normal Shape: 0.41 Loc: 109.00 Scale: 50.82
Other Root, Bulb or Tuberous Vegetables-White Radish
Normal Mean: 4.53 Std: 1.50
Mushrooms and Truffles
Log-Normal Shape: 0.54 Loc: 3.92 Scale: 30.85
Wheat-Durum
Log-Normal Shape: 0.10 Loc: -1949.99 Scale: 5640.59
Wheat-Other
Log-Normal Shape: 0.00 Loc: -71853179.80 Scale: 71869707.13
Maize
Log-Normal Shape: 0.31 Loc: 280.67 Scale: 5063.00
Barley-Beer
Log-Normal Shape: 0.32 Loc: -40.69 Scale: 563.78
Barley-Other
Log-Normal Shape: 0.04 Loc: -15877.74 Scale: 22971.63
Rye
Log-Normal Shape: 0.00 Loc: -1497649.79 Scale: 1497950.67
Oats
Log-Normal Shape: 0.78 Loc: 177.76 Scale: 61.10
Sorghum
Logistic Shape: 0.11 Loc: 0.07
Millet
Logistic Shape: 5.77 Loc: 0.73
Chick Peas-Dry
Log-Normal Shape: 0.16 Loc: 159.09 Scale: 375.86
Lentils-Dry,Red
Normal Mean: 375.83 Std: 102.21
Lentils-Dry,Green
Log-Normal Shape: 12.58 Loc: 20.00 Scale: 0.08
Soya Beans
Weibull_min Shape: 49201184.64 Loc: -2038378856.46 Scale: 2038378997.85
Groundnuts-In Shell
Log-Normal Shape: 1.06 Loc: 72.37 Scale: 44.06
Seed-Lin
Log-Normal Shape: 15.39 Loc: 0.00 Scale: 0.00
Seed-Rape and Colza
Weibull_min Shape: 16.44 Loc: -525.59 Scale: 641.68
Seed-Sesame
Log-Normal Shape: 0.42 Loc: 11.82 Scale: 6.74
Seed-Sunflower,Oil Production
Log-Normal Shape: 0.26 Loc: -387.01 Scale: 1779.50
Probability Density
Production (Thousands ton)



Seed-Hemp
Log-Normal
Shape: 16.73
Loc: 0.00
Scale: 0.00
Seed-Poppy
Log-Normal
Shape: 0.36
Loc: -9.25
Scale: 27.69
Seed-Safflower Seed
Normal
Mean: 27.23
Std: 20.25
Rice-Not Husked
Weibull_min
Shape: 16581769.42
Loc: -1629913820.25
Scale: 1629914731.06
Potatoes
Log-Normal
Shape: 0.52
Loc: 3617.40
Scale: 999.58
Potatoes-Sweet
Weibull_min
Shape: 0.54
Loc: 0.25
Scale: 15.60
Other Edible Roots and Tubers-Jerusalem Artichokes
Weibull_min
Shape: 53.16
Loc: -17.58
Scale: 18.58
Other Edible Roots and Tubers-Salep
Empirical
KDE
Sugar Beet
Log-Normal
Shape: 0.31
Loc: 7531.76
Scale: 9660.71
Sugar Beet Seeds
Log-Normal
Shape: 9.40
Loc: 1.39
Scale: 0.03
Sugar Cane
Normal
Mean: 0.19
Std: 0.08
Tobacco-Unmanufactured
Log-Normal
Shape: 0.22
Loc: -10.75
Scale: 93.14
Probability Density
Production (Thousands ton)

C. CV VALUES FOR AGRICULTURAL RESIDUE PROFILE

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Wheat-Durum	Field	Straw	25,13	15,19	19,71	Constant	Constant		RPR	19,71
Wheat-Other	Field	Straw	20,92	6,46	19,85	Constant	Constant		RPR	19,85
Maize	Field	Stalk	35,56	29,42	19,48	Constant	Constant		Production	29,42
Barley-Other	Field	Straw	15,62	14,01	6,81	Constant	Constant		Production	14,01
Barley-Other	Field	Stalk	15,88	13,83	7,70	Constant	Constant		Production	13,83
Barley-Beer	Field	Straw	34,63	33,90	6,92	Constant	Constant		Production	33,90
Barley-Beer	Field	Stalk	35,67	34,70	7,71	Constant	Constant		Production	34,70
Rye	Field	Straw	17,15	15,24	7,86	Constant	Constant		Production	15,24
Oats	Field	Straw	25,57	24,55	6,69	Constant	Constant		Production	24,55
Sorghum	Field	Stalk	65,26	64,08	10,16	Constant	Constant		Production	64,08
Millet	Field	Straw	24,57	21,29	12,05	Constant	Constant		Production	21,29
Chick Peas-Dry	Field	Straw	11,67	11,43	2,76	Constant	Constant		Production	11,43
Chick Peas-Dry	Field	Stem, Leave	11,44	11,44	Constant	Constant	Constant		Production	11,44
Lentils-Dry,Red	Field	Stem, Leave	27,93	27,93	Constant	Constant	Constant		Production	27,93
Lentils-Dry,Green	Field	Stem, Leave	38,70	38,70	Constant	Constant	Constant		Production	38,70
Soya Beans	Field	Stem, Leave	68,02	68,02	Constant	Constant	Constant		Production	68,02
Soya Beans	Field	Straw	72,69	67,34	21,68	Constant	Constant		Production	67,34
Groundnuts-In Shell	Field	Straw	37,40	37,36	1,51	Constant	Constant		Production	37,36
Seed-Rape and Colza	Field	Stalk	67,05	67,03	1,94	Constant	Constant		Production	67,03
Seed-Sesame	Field	Trash	17,18	17,18	Constant	Constant	Constant		Production	17,18
Seed-Sunflower,Oil Production	Field	Stalk	39,57	32,95	21,41	Constant	Constant		Production	32,95
Seed-Hemp	Field	Stem, Leave	208,24	208,24	Constant	Constant	Constant		Production	208,24
Rice-Not Husked	Field	Straw	70,05	66,95	15,95	Constant	Constant		Production	66,95
Potatoes	Field	Vine	24,63	13,69	20,36	Constant	Constant		RPR	20,36
Potatoes	Field	Tuber	13,74	13,74	Constant	Constant	Constant		Production	13,74
Potatoes-Sweet	Field	Vine	72,27	67,52	20,26	Constant	Constant		Production	67,52
Potatoes-Sweet	Field	Tuber	67,53	67,53	Constant	Constant	Constant		Production	67,53
Other Edible Roots and Tubers-Jerusalem Artichokes	Field	Vine	71,70	67,41	20,30	Constant	Constant		Production	67,41

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Other Edible Roots and Tubers-Jerusalem Artichokes	Field	Tuber	69,27	69,27	Constant	Constant	Constant		Production	69,27
Other Edible Roots and Tubers-Salep	Field	Vine	29,10	20,27	20,45	Constant	Constant		RPR	20,45
Other Edible Roots and Tubers-Salep	Field	Tuber	20,25	20,25	Constant	Constant	Constant		Production	20,25
Sugar Beet	Field	Leave	25,81	18,14	17,97	Constant	Constant		Production	18,14
Sugar Beet Seeds	Field	Leave	28,32	22,17	17,75	Constant	Constant		Production	22,17
Sugar Cane	Field	Top, Leave	44,52	40,91	16,73	Constant	Constant		Production	40,91
Tobacco-Unmanufactured	Field	Stalk, Stem	29,16	26,32	12,19	Constant	Constant		Production	26,32
Cabbages-White	Field	Foliage, Stem	68,23	68,23	Constant	Constant	Constant		Production	68,23
Cabbages-Red	Field	Foliage, Stem	29,95	29,95	Constant	Constant	Constant		Production	29,95
Cabbages-Black	Field	Foliage, Stem	19,39	19,39	Constant	Constant	Constant		Production	19,39
Cabbages-Brussels Sprouts	Field	Foliage, Stem	37,20	37,20	Constant	Constant	Constant		Production	37,20
Tomatoes,Production	Field	Stem, Leave	23,02	23,02	Constant	Constant	Constant		Production	23,02
Carrots and Turnips-Carrots	Field	Vine	28,97	20,65	20,08	Constant	Constant		Production	20,65
Carrots and Turnips-Carrots	Field	Tuber	20,38	20,38	Constant	Constant	Constant		Production	20,38
Carrots and Turnips-Turnips	Field	Vine	70,29	66,82	20,29	Constant	Constant		Production	66,82
Carrots and Turnips-Turnips	Field	Tuber	67,33	67,33	Constant	Constant	Constant		Production	67,33
Other Root, Bulb or Tuberous Vegetables-Red Radish	Field	Vine	24,72	13,78	20,10	Constant	Constant		RPR	20,10
Other Root, Bulb or Tuberous Vegetables-Red Radish	Field	Tuber	13,63	13,63	Constant	Constant	Constant		Production	13,63
Other Root, Bulb or Tuberous Vegetables-Celeriac	Field	Vine	73,21	69,25	20,44	Constant	Constant		Production	69,25
Other Root, Bulb or Tuberous Vegetables-Celeriac	Field	Tuber	67,34	67,34	Constant	Constant	Constant		Production	67,34
Other Root, Bulb or Tuberous Vegetables-Beetroot	Field	Vine	53,31	48,59	20,31	Constant	Constant		Production	48,59
Other Root, Bulb or Tuberous Vegetables-Beetroot	Field	Tuber	46,82	46,82	Constant	Constant	Constant		Production	46,82
Other Root, Bulb or Tuberous Vegetables-Horseradish	Field	Vine	25,89	15,45	20,24	Constant	Constant		RPR	20,24
Other Root, Bulb or Tuberous Vegetables-Horseradish	Field	Tuber	15,45	15,45	Constant	Constant	Constant		Production	15,45
Other Root, Bulb or Tuberous Vegetables-White Radish	Field	Vine	39,99	33,70	20,50	Constant	Constant		Production	33,70
Other Root, Bulb or Tuberous Vegetables-White Radish	Field	Tuber	34,39	34,39	Constant	Constant	Constant		Production	34,39
Grapes-Seedless,for Drying	Field	Prunings	13,38	11,27	7,32	Constant	Constant		Production	11,27
Grapes-Wine industry	Field	Prunings	13,37	11,17	7,20	Constant	Constant		Production	11,17

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Grapes-Seeded,for Drying	Field	Prunings	14,87	12,94	7,40	Constant	Constant		Production	12,94
Bananas and Plantains	Field	Stem, Leave	68,50	68,50	Constant	Constant	Constant		Production	68,50
Figs	Field	Prunings	19,21	14,56	12,18	Constant	Constant		Production	14,56
Pomelos and Grapefruits	Field	Prunings	19,70	19,70	Constant	Constant	Constant		Production	19,70
Lemons and Limes	Field	Prunings	46,49	44,71	11,95	Constant	Constant		Production	44,71
Oranges-Washington	Field	Prunings	32,60	14,37	28,95	Constant	Constant		RPR	28,95
Oranges-Other	Field	Prunings	44,11	32,41	29,44	Constant	Constant		Production	32,41
Oranges-Navel	Field	Prunings	33,39	15,79	28,89	Constant	Constant		RPR	28,89
Tangarines, mandarins, clementines-Other	Field	Prunings	80,54	73,07	26,68	Constant	Constant		Production	73,07
Tangarines, mandarins, clementines-Satsuma	Field	Prunings	41,04	30,32	26,65	Constant	Constant		Production	30,32
Tangarines, mandarins, clementines-Klemantin	Field	Prunings	31,20	16,45	26,22	Constant	Constant		RPR	26,22
Tangarines, mandarins, clementines-King	Field	Prunings	38,65	26,45	26,83	Constant	Constant		RPR	26,83
Apples-Starking	Field	Prunings	25,11	17,56	17,95	Constant	Constant		RPR	17,95
Apples-Other	Field	Prunings	69,30	66,62	18,23	Constant	Constant		Production	66,62
Apples-Golden	Field	Prunings	26,36	19,27	18,01	Constant	Constant		Production	19,27
Apples-Amasya	Field	Prunings	25,41	17,62	18,04	Constant	Constant		RPR	18,04
Apples-Granny Smith	Field	Prunings	56,54	52,98	17,95	Constant	Constant		Production	52,98
Pears	Field	Prunings	26,69	19,37	17,53	Constant	Constant		Production	19,37
Quinces	Field	Prunings	32,11	29,32	12,26	Constant	Constant		Production	29,32
Apricots	Field	Prunings	43,34	30,77	29,49	Constant	Constant		Production	30,77
Apricots-Wild	Field	Prunings	44,68	32,15	29,26	Constant	Constant		Production	32,15
Cherries	Field	Prunings	39,49	30,13	24,24	Constant	Constant		Production	30,13
Sour Cherries	Field	Prunings	26,94	11,71	24,03	Constant	Constant		RPR	24,03
Peaches	Field	Prunings	26,80	22,09	14,40	Constant	Constant		Production	22,09
Nectarines	Field	Prunings	81,82	81,52	8,28	Constant	Constant		Production	81,52
Plums	Field	Prunings	18,99	16,81	8,37	Constant	Constant		Production	16,81
Loquat	Field	Prunings	18,37	13,88	12,12	Constant	Constant		Production	13,88
Other Pome Fruits and Stone Fruits-Cornelian Cherry	Field	Prunings	15,67	13,41	8,27	Constant	Constant		Production	13,41
Other Pome Fruits and Stone Fruits-Oleaster	Field	Prunings	11,72	8,20	8,20	Constant	Constant		RPR	8,20

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Other Pome Fruits and Stone Fruits-Jujube	Field	Prunings	85,86	85,24	8,31	Constant	Constant		Production	85,24
Kiwi Fruit	Field	Prunings	65,23	63,93	12,19	Constant	Constant		Production	63,93
Almonds	Field	Prunings	64,00	54,36	27,20	Constant	Constant		Production	54,36
Hazelnuts	Field	Prunings	20,71	20,71	Constant	Constant	Constant		Production	20,71
Pistachios	Field	Prunings	67,99	61,65	24,93	Constant	Constant		Production	61,65
Walnuts	Field	Prunings	35,12	35,12	Constant	Constant	Constant		Production	35,12
Other Tree and Bush Fruits-Pomegranate	Field	Prunings	53,18	51,12	11,89	Constant	Constant		Production	51,12
Other Tree and Bush Fruits-Persimmon	Field	Prunings	78,34	76,37	12,19	Constant	Constant		Production	76,37
Other Tree and Bush Fruits-Locust Bean	Field	Prunings	28,90	25,83	12,28	Constant	Constant		Production	25,83
Other Tree and Bush Fruits-Medlar	Field	Prunings	69,86	68,32	12,13	Constant	Constant		Production	68,32
Olives-Olive Oil	Field	Prunings	42,77	35,20	23,66	Constant	Constant		Production	35,20
Wheat-Durum	Agro-Industry	Husk	16,59	15,62	4,79	19,79	Constant	Constant	Moisture	19,79
Wheat-Durum	Agro-Industry	Bran	19,05	15,45	10,49	20,13	Constant	Constant	Moisture	20,13
Wheat-Other	Agro-Industry	Husk	8,69	6,61	4,71	19,85	Constant	Constant	Moisture	19,85
Wheat-Other	Agro-Industry	Bran	12,77	6,61	10,51	20,11	Constant	Constant	Moisture	20,11
Maize	Agro-Industry	Husk	32,92	29,64	13,37	19,87	Constant	Constant	Production	29,64
Maize	Agro-Industry	Cob	40,42	29,63	25,89	20,06	Constant	Constant	Production	29,63
Barley-Other	Agro-Industry	Husk	21,44	13,91	15,86	20,01	Constant	Constant	Moisture	20,01
Barley-Other	Agro-Industry	Bran	22,49	13,76	17,74	19,95	Constant	Constant	Moisture	19,95
Barley-Beer	Agro-Industry	Bagasse	34,88	34,57	3,76	19,86	Constant	Constant	Production	34,57
Barley-Beer	Agro-Industry	Spent barley grains	34,56	34,43	Constant	20,38	Constant	Constant	Production	34,43
Rye	Agro-Industry	Bran	23,11	15,29	16,72	20,03	Constant	Constant	Moisture	20,03
Oats	Agro-Industry	Husk	25,14	24,54	4,09	19,93	Constant	Constant	Production	24,54
Oats	Agro-Industry	Bran	24,64	24,44	Constant	19,53	Constant	Constant	Production	24,44
Chick Peas-Dry	Agro-Industry	Discarded seeds, hulls and dark or spotted seeds	25,60	11,51	22,12	19,96	Constant	2,19	RPR	22,12
Lentils-Dry,Red	Agro-Industry	Discarded seeds, hulls and dark or spotted seeds	35,89	27,94	22,00	19,73	Constant	2,24	Production	27,94
Lentils-Dry,Green	Agro-Industry	Discarded seeds, hulls and dark or spotted seeds	46,35	39,65	22,30	19,87	Constant	2,22	Production	39,65
Soya Beans	Agro-Industry	Shell	67,80	67,16	7,25	19,86	Constant	Constant	Production	67,16
Soya Beans	Agro-Industry	Cake	68,06	67,94	Constant	19,76	Constant	Constant	Production	67,94

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Groundnuts-In Shell	Agro-Industry	Shell	41,09	37,54	14,81	19,92	Constant	Constant	Production	37,54
Seed-Sunflower,Oil Production	Agro-Industry	Shell	34,08	33,90	Constant	19,97	Constant	Constant	Production	33,90
Rice-Not Husked	Agro-Industry	Husk	77,10	68,77	26,69	20,26	Constant	Constant	Production	68,77
Rice-Not Husked	Agro-Industry	Bran	69,68	68,96	6,67	20,10	Constant	Constant	Production	68,96
Potatoes	Agro-Industry	Peel	30,52	13,83	18,00	19,13	Constant	10,08	Moisture	19,13
Potatoes-Sweet	Agro-Industry	Peel	74,99	66,75	17,76	19,53	Constant	10,09	Production	66,75
Sugar Beet	Agro-Industry	Pulp	33,70	18,32	23,58	3,01	Constant	2,23	RPR	23,58
Sugar Cane	Agro-Industry	Pulp	52,04	41,79	23,54	3,03	Constant	Constant	Production	41,79
Tobacco-Unmanufactured	Agro-Industry	Solid waste (low grade tobacco and tobacco powder)	26,45	26,32	Constant	20,18	Constant	Constant	Production	26,32
Beans-Green	Agro-Industry	Shell	29,99	8,20	4,79	19,27	Constant	22,26	Industrial Process	22,26
Kidney Beans-Green	Agro-Industry	Shell	33,95	16,67	4,76	19,14	Constant	22,03	Industrial Process	22,03
Peas-Green	Agro-Industry	Shell	34,12	17,50	Constant	19,20	Constant	22,37	Industrial Process	22,37
Other Green Leguminous Vegetables-Broad Beans	Agro-Industry	Shell	31,73	13,42	Constant	19,43	Constant	22,38	Industrial Process	22,38
Other Green Leguminous Vegetables-Cow Pea	Agro-Industry	Shell	34,03	16,71	4,70	19,13	Constant	22,32	Industrial Process	22,32
Asparagus	Agro-Industry	Spear	161,48	150,84	6,61	18,92	Constant	22,20	Production	150,84
Cabbages-White	Agro-Industry	Leaves, stem, curd	76,57	68,04	8,39	3,03	Constant	22,32	Production	68,04
Cabbages-Red	Agro-Industry	Leaves, stem, curd	42,66	30,41	8,35	3,02	Constant	22,33	Production	30,41
Cabbages-Black	Agro-Industry	Leaves, stem, curd	34,81	19,54	8,31	3,03	Constant	22,06	Industrial Process	22,06
Cabbages-Brussels Sprouts	Agro-Industry	Leaves, stem, curd	48,98	38,16	8,32	3,06	Constant	22,06	Production	38,16
Cauliflowers	Agro-Industry	Leaves, stem, curd	37,48	24,79	8,38	2,99	Constant	22,25	Production	24,79
Broccoli	Agro-Industry	Leaves, stem, curd	79,55	73,00	6,70	3,06	Constant	22,44	Production	73,00
Lettuce and Chicory-Curly	Agro-Industry	Leaves, stem, curd	36,02	23,39	Constant	3,03	Constant	22,23	Production	23,39
Lettuce and Chicory-Head	Agro-Industry	Leaves, stem, curd	27,30	5,16	Constant	3,08	Constant	22,06	Industrial Process	22,06
Lettuce and Chicory-Iceberg	Agro-Industry	Leaves, stem, curd	41,57	31,04	Constant	3,07	Constant	22,05	Production	31,04
Spinach	Agro-Industry	Leaves, stem, curd	26,97	4,37	Constant	3,05	Constant	22,27	Industrial Process	22,27
Artichokes	Agro-Industry	Leaves, stem, curd	28,20	8,98	2,55	3,05	Constant	22,06	Industrial Process	22,06
Other Leafy or Stem Vegetables-Parsley	Agro-Industry	Leaves, stem, curd	45,10	35,96	Constant	3,03	Constant	21,99	Production	35,96
Other Leafy or Stem Vegetables-Rocket	Agro-Industry	Leaves, stem, curd	110,66	101,08	Constant	3,04	Constant	22,30	Production	101,08
Other Leafy or Stem Vegetables-Mint	Agro-Industry	Leaves, stem, curd	49,93	41,39	Constant	3,04	Constant	22,36	Production	41,39

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Other Leafy or Stem Vegetables-Dill	Agro-Industry	Leaves, stem, curd	77,54	68,98	Constant	3,00	Constant	22,44	Production	68,98
Other Leafy or Stem Vegetables-Purslane	Agro-Industry	Leaves, stem, curd	67,97	59,31	Constant	2,99	Constant	22,37	Production	59,31
Other Leafy or Stem Vegetables-Cress	Agro-Industry	Leaves, stem, curd	75,90	67,95	Constant	3,04	Constant	22,11	Production	67,95
Other Leafy or Stem Vegetables-Chards	Agro-Industry	Leaves, stem, curd	32,15	17,89	Constant	3,02	Constant	22,03	Industrial Process	22,03
Other Leafy or Stem Vegetables-Celery	Agro-Industry	Leaves, stem, curd	37,13	25,63	Constant	3,04	Constant	22,11	Production	25,63
Watermelons	Agro-Industry	Peel	75,99	68,17	5,15	3,05	Constant	22,08	Production	68,17
Watermelons	Agro-Industry	Seed	74,30	67,35	Constant	3,07	Constant	22,22	Production	67,35
Watermelons	Agro-Industry	Flesh	75,51	67,74	2,89	3,02	Constant	21,96	Production	67,74
Cantaloupes and Other Melons	Agro-Industry	Peel	29,24	6,51	9,19	3,04	Constant	22,14	Industrial Process	22,14
Cantaloupes and Other Melons	Agro-Industry	Seed	30,10	6,41	11,47	3,04	Constant	22,32	Industrial Process	22,32
Cantaloupes and Other Melons	Agro-Industry	Flesh	27,68	6,48	3,65	3,02	Constant	22,12	Industrial Process	22,12
Chilles and Peppers-Paprika	Agro-Industry	Peel, seed, placenta, peduncle	56,03	37,46	27,63	2,99	Constant	22,42	Production	37,46
Chilles and Peppers-Thin Tapered	Agro-Industry	Peel, seed, placenta, peduncle	41,62	11,31	28,22	3,03	Constant	22,33	RPR	28,22
Chilles and Peppers-Stuffing	Agro-Industry	Peel, seed, placenta, peduncle	39,94	4,78	28,09	3,05	Constant	22,26	RPR	28,09
Chilles and Peppers-Charleston	Agro-Industry	Peel, seed, placenta, peduncle	42,97	15,73	28,30	3,04	Constant	22,01	RPR	28,30
Eggplants	Agro-Industry	Peel	27,00	4,65	Constant	3,00	Constant	22,04	Industrial Process	22,04
Eggplants	Agro-Industry	Pulp	26,82	4,65	Constant	3,03	Constant	22,12	Industrial Process	22,12
Tomatoes,Production	Agro-Industry	Peel	32,85	22,79	18,20	3,04	Constant	Constant	Production	22,79
Tomatoes,Production	Agro-Industry	Seed	27,46	22,82	2,56	3,05	Constant	Constant	Production	22,82
Tomatoes,Production	Agro-Industry	Pulp	35,56	22,53	22,32	3,02	Constant	Constant	Production	22,53
Pumpkins,Squash and Gourds-Pumpkin	Agro-Industry	Peel	37,97	9,66	23,89	3,04	Constant	22,33	RPR	23,89
Pumpkins,Squash and Gourds-Pumpkin	Agro-Industry	Seed	28,94	9,55	5,76	3,04	Constant	21,82	Industrial Process	21,82
Pumpkins,Squash and Gourds-Pumpkin	Agro-Industry	Flesh	28,61	9,57	0,91	3,05	Constant	22,35	Industrial Process	22,35
Pumpkins,Squash and Gourds-Bitter Melon	Agro-Industry	Peel	43,01	21,86	24,04	3,02	Constant	21,87	RPR	24,04
Pumpkins,Squash and Gourds-Bitter Melon	Agro-Industry	Seed	35,66	21,85	5,79	2,99	Constant	22,39	Industrial Process	22,39
Pumpkins,Squash and Gourds-Bitter Melon	Agro-Industry	Pulp	34,79	21,63	0,90	3,06	Constant	22,14	Industrial Process	22,14
Carrots and Turnips-Carrots	Agro-Industry	Pulp	38,80	20,53	17,85	3,05	Constant	22,16	Industrial Process	22,16

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Carrots and Turnips-Turnips	Agro-Industry	Pulp	80,42	67,86	18,26	3,05	Constant	22,18	Production	67,86
Garlic-Dry	Agro-Industry	Straw, peel	39,04	23,01	9,93	19,52	Constant	22,44	Production	23,01
Onions-Dry	Agro-Industry	Straw, peel	37,50	12,88	19,24	19,40	Constant	22,39	Industrial Process	22,39
Leeks and Other Alliaceous Vegetables-Leek	Agro-Industry	Stem	36,46	18,69	10,05	19,09	Constant	22,42	Industrial Process	22,42
Grapes-Seedless,for Drying	Agro-Industry	Stalk	26,68	11,19	16,75	19,35	Constant	Constant	Moisture	19,35
Grapes-Wine industry	Agro-Industry	Stalk	24,84	11,04	16,54	3,07	Constant	Constant	RPR	16,54
Grapes-Wine industry	Agro-Industry	Peel	18,24	11,03	3,19	3,02	Constant	Constant	Production	11,03
Grapes-Wine industry	Agro-Industry	Seed	27,92	10,92	21,00	3,03	Constant	Constant	RPR	21,00
Grapes-Wine industry	Agro-Industry	Pulp	25,60	11,12	18,25	3,02	Constant	Constant	RPR	18,25
Grapes-Seeded,for Drying	Agro-Industry	Stalk	27,85	13,17	16,65	18,98	Constant	Constant	Moisture	18,98
Avocados	Agro-Industry	Peel	197,64	191,97	7,13	3,05	Constant	12,53	Production	191,97
Avocados	Agro-Industry	Seed	192,09	189,54	7,12	3,00	Constant	12,72	Production	189,54
Avocados	Agro-Industry	Pulp	206,09	199,05	1,94	3,00	Constant	12,56	Production	199,05
Bananas and Plantains	Agro-Industry	Peel	72,13	68,05	2,22	3,08	Constant	12,47	Production	68,05
Pomelos and Grapefruits	Agro-Industry	Peel	33,97	19,87	Constant	3,00	Constant	22,17	Industrial Process	22,17
Pomelos and Grapefruits	Agro-Industry	Seed	33,70	19,68	Constant	3,01	Constant	21,94	Industrial Process	21,94
Pomelos and Grapefruits	Agro-Industry	Pulp and rag	33,75	20,02	5,50	3,04	Constant	21,93	Industrial Process	21,93
Lemons and Limes	Agro-Industry	Peel	48,59	44,39	Constant	3,01	Constant	12,48	Production	44,39
Lemons and Limes	Agro-Industry	Seed	49,87	45,28	Constant	3,03	Constant	12,92	Production	45,28
Lemons and Limes	Agro-Industry	Pulp and rag	50,03	44,81	5,57	3,02	Constant	12,63	Production	44,81
Oranges-Washington	Agro-Industry	Peel	26,06	14,50	Constant	3,02	Constant	16,25	Industrial Process	16,25
Oranges-Washington	Agro-Industry	Seed	26,07	14,28	Constant	3,04	Constant	15,99	Industrial Process	15,99
Oranges-Washington	Agro-Industry	Pulp and rag	26,39	14,45	5,52	2,99	Constant	15,99	Industrial Process	15,99
Oranges-Other	Agro-Industry	Peel	39,60	32,76	Constant	3,00	Constant	15,90	Production	32,76
Oranges-Other	Agro-Industry	Seed	39,85	32,84	Constant	3,00	Constant	16,21	Production	32,84
Oranges-Other	Agro-Industry	Pulp and rag	40,76	33,56	5,57	2,99	Constant	16,07	Production	33,56
Oranges-Navel	Agro-Industry	Peel	27,35	16,05	Constant	3,03	Constant	16,00	Production	16,05
Oranges-Navel	Agro-Industry	Seed	27,28	16,08	Constant	3,02	Constant	16,17	Industrial Process	16,17
Oranges-Navel	Agro-Industry	Pulp and rag	27,90	16,02	5,57	3,05	Constant	16,10	Industrial Process	16,10

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Tangarines, mandarins, clementines-Other	Agro-Industry	Peel	87,61	74,76	Constant	3,01	Constant	33,29	Production	74,76
Tangarines, mandarins, clementines-Other	Agro-Industry	Seed	86,71	74,20	Constant	3,04	Constant	33,99	Production	74,20
Tangarines, mandarins, clementines-Other	Agro-Industry	Pulp and rag	86,37	73,42	5,56	3,07	Constant	33,75	Production	73,42
Tangarines, mandarins, clementines-Satsuma	Agro-Industry	Peel	49,68	30,85	Constant	3,05	Constant	33,20	Industrial Process	33,20
Tangarines, mandarins, clementines-Satsuma	Agro-Industry	Seed	48,81	30,74	Constant	3,04	Constant	33,82	Industrial Process	33,82
Tangarines, mandarins, clementines-Satsuma	Agro-Industry	Pulp and rag	49,40	30,76	5,52	3,05	Constant	33,24	Industrial Process	33,24
Tangarines, mandarins, clementines-Klemantin	Agro-Industry	Peel	40,07	16,95	Constant	3,02	Constant	33,08	Industrial Process	33,08
Tangarines, mandarins, clementines-Klemantin	Agro-Industry	Seed	41,11	16,62	Constant	3,03	Constant	33,32	Industrial Process	33,32
Tangarines, mandarins, clementines-Klemantin	Agro-Industry	Pulp and rag	41,64	17,04	5,51	3,04	Constant	33,57	Industrial Process	33,57
Tangarines, mandarins, clementines-King	Agro-Industry	Peel	44,99	26,11	Constant	2,99	Constant	32,96	Industrial Process	32,96
Tangarines, mandarins, clementines-King	Agro-Industry	Seed	45,92	26,54	Constant	3,01	Constant	33,24	Industrial Process	33,24
Tangarines, mandarins, clementines-King	Agro-Industry	Pulp and rag	46,72	26,58	5,53	3,04	Constant	33,17	Industrial Process	33,17
Other Citrus Fruits	Agro-Industry	Peel	26,47	17,92	Constant	3,01	Constant	12,75	Production	17,92
Other Citrus Fruits	Agro-Industry	Seed	26,52	18,03	Constant	2,99	Constant	12,81	Production	18,03
Other Citrus Fruits	Agro-Industry	Pulp and rag	27,09	18,02	5,61	3,03	Constant	12,67	Production	18,02
Apples-Starking	Agro-Industry	Peel	26,66	17,95	Constant	3,03	Constant	12,74	Production	17,95
Apples-Starking	Agro-Industry	Seed	28,66	17,75	11,12	3,05	Constant	12,61	Production	17,75
Apples-Starking	Agro-Industry	Pulp	28,21	17,75	9,00	3,06	Constant	12,71	Production	17,75
Apples-Other	Agro-Industry	Peel	70,62	68,03	Constant	3,07	Constant	12,73	Production	68,03
Apples-Other	Agro-Industry	Seed	72,06	66,59	11,20	3,00	Constant	12,74	Production	66,59
Apples-Other	Agro-Industry	Pulp	72,52	69,01	9,10	3,07	Constant	12,52	Production	69,01
Apples-Golden	Agro-Industry	Peel	27,63	19,35	Constant	3,06	Constant	12,78	Production	19,35
Apples-Golden	Agro-Industry	Seed	29,91	19,56	11,07	3,03	Constant	12,78	Production	19,56
Apples-Golden	Agro-Industry	Pulp	29,04	19,60	9,00	3,05	Constant	12,53	Production	19,60
Apples-Amasya	Agro-Industry	Peel	26,21	17,15	Constant	3,05	Constant	12,72	Production	17,15
Apples-Amasya	Agro-Industry	Seed	28,78	17,10	10,93	3,05	Constant	12,73	Production	17,10
Apples-Amasya	Agro-Industry	Pulp	28,09	17,60	9,07	3,12	Constant	12,64	Production	17,60
Apples-Granny Smith	Agro-Industry	Peel	56,19	52,38	Constant	3,03	Constant	12,75	Production	52,38

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Apples-Granny Smith	Agro-Industry	Seed	57,67	52,09	11,09	3,06	Constant	12,64	Production	52,09
Apples-Granny Smith	Agro-Industry	Pulp	56,89	52,09	9,06	3,02	Constant	12,53	Production	52,09
Pears	Agro-Industry	Peel	27,76	19,54	Constant	3,02	Constant	12,69	Production	19,54
Pears	Agro-Industry	Seed	29,52	19,01	11,04	3,02	Constant	12,62	Production	19,01
Pears	Agro-Industry	Pulp	29,16	19,52	9,21	3,02	Constant	12,78	Production	19,52
Quinces	Agro-Industry	Peel	35,09	28,84	Constant	3,02	Constant	12,62	Production	28,84
Quinces	Agro-Industry	Seed	37,44	29,30	11,09	3,02	Constant	12,55	Production	29,30
Quinces	Agro-Industry	Pulp	36,26	29,24	9,05	3,05	Constant	12,57	Production	29,24
Apricots	Agro-Industry	Peel	39,24	30,52	Constant	3,01	Constant	17,79	Production	30,52
Apricots	Agro-Industry	Seed	40,92	30,92	10,82	3,04	Constant	17,68	Production	30,92
Apricots	Agro-Industry	Pulp	38,75	30,82	Constant	3,03	Constant	18,07	Production	30,82
Apricots-Wild	Agro-Industry	Peel	40,13	31,99	Constant	3,03	Constant	17,86	Production	31,99
Apricots-Wild	Agro-Industry	Seed	41,46	32,15	10,59	2,99	Constant	17,98	Production	32,15
Apricots-Wild	Agro-Industry	Pulp	40,66	32,42	Constant	3,01	Constant	17,98	Production	32,42
Cherries	Agro-Industry	Seed	45,10	30,10	22,21	3,04	Constant	17,76	Production	30,10
Cherries	Agro-Industry	Pulp	40,88	30,91	10,13	3,00	Constant	17,83	Production	30,91
Sour Cherries	Agro-Industry	Seed	34,65	12,00	22,08	3,05	Constant	18,13	RPR	22,08
Sour Cherries	Agro-Industry	Pulp	27,74	11,77	9,99	3,00	Constant	17,80	Industrial Process	17,80
Peaches	Agro-Industry	Peel	36,17	22,28	15,41	3,05	Constant	17,93	Production	22,28
Peaches	Agro-Industry	Seed	33,27	22,39	7,13	3,00	Constant	18,01	Production	22,39
Peaches	Agro-Industry	Pulp	32,14	22,20	Constant	3,01	Constant	17,66	Production	22,20
Nectarines	Agro-Industry	Peel	82,48	76,55	15,90	3,01	Constant	17,87	Production	76,55
Nectarines	Agro-Industry	Seed	83,37	77,26	7,21	3,02	Constant	18,27	Production	77,26
Nectarines	Agro-Industry	Pulp	80,99	76,57	Constant	3,05	Constant	17,99	Production	76,57
Plums	Agro-Industry	Peel	33,32	16,77	15,43	3,06	Constant	17,95	Industrial Process	17,95
Plums	Agro-Industry	Seed	29,63	16,87	7,14	3,04	Constant	17,90	Industrial Process	17,90
Plums	Agro-Industry	Pulp	28,87	17,03	Constant	3,01	Constant	17,77	Industrial Process	17,77
Loquat	Agro-Industry	Peel	31,64	13,63	15,61	3,05	Constant	18,24	Industrial Process	18,24
Loquat	Agro-Industry	Seed	31,61	13,78	15,54	3,03	Constant	18,10	Industrial Process	18,10
Loquat	Agro-Industry	Pulp	27,15	13,57	Constant	3,04	Constant	17,83	Industrial Process	17,83

Product Name	Residue Source	Residue Type	CV Available Dry Residue Ratio (%)	CV_PROD (%)	CV_RPR (%)	CV_MOIST (%)	CV_AVAIL (%)	CV_IND (%)	Highest CV Source	Highest CV (%)
Other Pome Fruits and Stone Fruits-Cornelian Cherry	Agro-Industry	Pulp	26,60	13,34	Constant	2,99	Constant	17,87	Industrial Process	17,87
Other Pome Fruits and Stone Fruits-Oleaster	Agro-Industry	Pulp	26,34	8,25	Constant	19,27	Constant	17,84	Moisture	19,27
Other Pome Fruits and Stone Fruits-Jujube	Agro-Industry	Pulp	90,21	82,66	Constant	19,50	Constant	17,84	Production	82,66
Kiwi Fruit	Agro-Industry	Peel	69,80	64,62	11,02	3,01	Constant	12,62	Production	64,62
Kiwi Fruit	Agro-Industry	Pulp	71,58	65,30	11,21	3,04	Constant	12,58	Production	65,30
Raspberries	Agro-Industry	Pulp	47,23	41,43	6,65	3,04	Constant	12,68	Production	41,43
Strawberries	Agro-Industry	Pulp	47,23	41,24	6,72	3,02	Constant	12,53	Production	41,24
Other Berries-Mulberry	Agro-Industry	Pulp	72,14	68,80	6,62	3,08	Constant	12,58	Production	68,80
Other Berries-Blackberry	Agro-Industry	Pulp	72,34	67,48	6,66	3,01	Constant	12,47	Production	67,48
Other Berries-Blueberry	Agro-Industry	Pulp	72,90	68,31	6,71	3,01	Constant	12,60	Production	68,31
Almonds	Agro-Industry	Shell	55,47	53,91	12,57	19,90	Constant	Constant	Production	53,91
Chestnuts	Agro-Industry	Shell	15,87	13,92	7,07	20,07	Constant	Constant	Moisture	20,07
Hazelnuts	Agro-Industry	Shell	26,54	20,81	16,32	20,23	Constant	0,86	Production	20,81
Pistachios	Agro-Industry	Shell	63,43	62,40	9,67	19,96	Constant	Constant	Production	62,40
Walnuts	Agro-Industry	Shell	40,19	35,73	18,08	20,23	Constant	Constant	Production	35,73
Other Tree and Bush Fruits-Pomegranate	Agro-Industry	Peel	55,23	50,58	3,68	3,02	Constant	12,62	Production	50,58
Other Tree and Bush Fruits-Pomegranate	Agro-Industry	Seed	54,23	49,67	Constant	3,00	Constant	12,71	Production	49,67
Other Tree and Bush Fruits-Persimmon	Agro-Industry	Seed	79,73	75,90	6,56	3,01	Constant	12,81	Production	75,90
Other Tree and Bush Fruits-Persimmon	Agro-Industry	Pulp	81,92	77,81	Constant	3,02	Constant	12,62	Production	77,81
Other Tree and Bush Fruits-Locust Bean	Agro-Industry	Seed	33,94	25,68	Constant	19,17	Constant	12,66	Production	25,68
Other Tree and Bush Fruits-Locust Bean	Agro-Industry	Pulp	34,24	25,48	Constant	19,44	Constant	12,80	Production	25,48
Other Tree and Bush Fruits-Medlar	Agro-Industry	Peel	72,32	67,43	Constant	19,08	Constant	12,78	Production	67,43
Other Tree and Bush Fruits-Medlar	Agro-Industry	Seed	76,93	68,49	20,01	19,23	Constant	12,75	Production	68,49
Other Tree and Bush Fruits-Medlar	Agro-Industry	Pulp	71,81	67,08	Constant	18,84	Constant	12,55	Production	67,08
Olives-Olive Oil	Agro-Industry	Peel	38,77	34,26	Constant	19,38	Constant	Constant	Production	34,26
Olives-Olive Oil	Agro-Industry	Seed	45,34	35,32	20,35	19,29	Constant	Constant	Production	35,32
Olives-Olive Oil	Agro-Industry	Pulp	42,59	35,94	11,06	19,57	Constant	Constant	Production	35,94
Tea-Leaves	Agro-Industry	Pulp	20,10	9,70	Constant	19,30	Constant	Constant	Moisture	19,30

D. SFE SCORE, BIOACTIVE SCORE AND AHP-TOPSIS RESULTS

Product	**Residue Source**	**Residue**	**Mean Available Dry Residue (ton)**	**CV Ratio**	**SFE Score**	**Bioactive Score**	**TOPSIS Score**	**TOPSIS Rank**
grape	Agro-Industry	seed	1113,3	0,2792	10,4740	31,4835	0,8548	1
grape	Agro-Industry	pulp	4028,0	0,2560	9,3779	30,9270	0,8395	2
tomato	Agro-Industry	pulp	64561,6	0,3556	9,2431	28,8546	0,8203	3
tomato	Agro-Industry	peel	35140,6	0,3285	8,1909	30,0545	0,8153	4
olive	Field	pruning	100590,1	0,4277	9,7685	27,4442	0,8071	5
olive	Agro-Industry	pulp	235689,5	0,4259	8,4966	28,0579	0,8036	6
rice	Agro-Industry	bran	58774,9	0,6968	12,0287	24,8359	0,7687	7
pumpkin	Agro-Industry	seed	69,6	0,2894	8,1610	25,1241	0,7406	8
tea	Agro-Industry	pulp	91164,5	0,2010	10,7032	23,0083	0,7261	9
tomato	Agro-Industry	seed	35009,2	0,2746	7,7632	24,0809	0,7147	10
orange	Agro-Industry	peel	5601,8	0,2402	9,7685	22,9287	0,7135	11
pomegranate	Agro-Industry	peel	3665,1	0,5523	7,2156	23,5338	0,6922	12
blackberry	Agro-Industry	pulp	14,1	0,7234	8,1870	22,2890	0,6764	13
strawberry	Agro-Industry	pulp	2032,0	0,4723	8,3926	21,8544	0,6716	14
wheat	Agro-Industry	bran	1883485,9	0,1219	8,5062	19,7572	0,6510	15
apple	Agro-Industry	pulp	5282,8	0,2105	7,2153	20,0062	0,6159	16
pumpkin	Agro-Industry	peel	169,0	0,3797	4,7530	21,1271	0,6053	17
walnut	Agro-Industry	shell	45284,5	0,4019	5,8844	19,5055	0,5852	18
cherry	Agro-Industry	seed	2968,4	0,4510	8,0207	18,0585	0,5774	19
banana	Agro-Industry	peel	3089,3	0,7213	4,7439	19,9448	0,5756	20
orange	Agro-Industry	pulp	11260,3	0,2432	7,1636	18,0267	0,5681	21
melon	Agro-Industry	seed	1852,8	0,3010	8,3583	16,8319	0,5535	22
pomegranate	Agro-Industry	seed	819,5	0,5423	8,1988	16,7651	0,5475	23
olive	Agro-Industry	seed	160725,9	0,4534	6,5354	15,3908	0,4956	24
grape	Agro-Industry	stalk	15378,5	0,2295	2,2590	17,5931	0,4948	25
grape	Agro-Industry	peel	2533,7	0,1824	6,0206	15,5437	0,4942	26
raspberry	Agro-Industry	pulp	21,2	0,4723	9,0571	13,7853	0,4883	27
onion	Agro-Industry	straw, peel	31338,4	0,3750	5,9947	15,1547	0,4824	28
citrus	Agro-Industry	pulp	32,1	0,2709	5,5134	15,3046	0,4808	29
avocado	Agro-Industry	pulp	117,9	2,0609	8,1870	13,5085	0,4531	30
sour cherry	Agro-Industry	pulp	1055,1	0,2774	5,5452	13,4193	0,4357	31
cherry	Agro-Industry	pulp	3068,7	0,4088	5,5452	13,4193	0,4338	32
grape	Field	pruning	159856,2	0,1067	4,1198	13,7766	0,4299	33
pumpkin	Agro-Industry	flesh	1390,8	0,2861	5,8377	12,8430	0,4257	34
citrus	Agro-Industry	peel	16,0	0,2647	7,1636	11,9479	0,4233	35
asparagus	Agro-Industry	spear	13,1	1,6148	5,8377	13,2711	0,4192	36
avocado	Agro-Industry	seed	29,8	1,9209	7,4593	12,4149	0,4187	37
apple	Agro-Industry	peel	963,5	0,2007	5,4811	12,5782	0,4159	38
carrot	Agro-Industry	pulp	3301,7	0,3880	3,2677	13,7243	0,4131	39
peach	Agro-Industry	seed	2262,6	0,3327	4,8648	12,6290	0,4070	40
broccoli	Agro-Industry	leave, stem, curd	698,3	0,7955	5,1891	12,6063	0,4038	41
hemp	Field	stem, leave	14,5	2,0824	8,8333	10,6082	0,3977	42
potato	Agro-Industry	peel	30129,8	0,3052	4,8610	12,1576	0,3963	43
quince	Agro-Industry	seed	85,1	0,3744	3,2189	13,0123	0,3954	44
avocado	Agro-Industry	peel	24,6	1,9764	7,4593	11,3447	0,3935	45
pepper	Agro-Industry	peel, seed	4565,3	0,3470	5,5452	11,5894	0,3911	46

apricot	Agro-Industry	seed	4719,8	0,4088	2,5085	13,0082	0,3870	47
lemon	Agro-Industry	peel	5904,1	0,4859	6,6519	10,8068	0,3866	48
grapefruit	Agro-Industry	peel	1070,0	0,3397	3,2189	12,4812	0,3831	49
tobacco	Agro-Industry	waste	11836,6	0,2645	6,7770	10,0819	0,3759	50
chestnut	Agro-Industry	shell	2199,1	0,1587	5,6330	10,6223	0,3732	51
sour cherry	Agro-Industry	seed	1027,3	0,3465	6,0354	10,0912	0,3636	52
blueberry	Agro-Industry	pulp	9,0	0,7290	6,1620	9,8463	0,3534	53
loquat	Agro-Industry	peel	27,8	0,3164	3,8451	10,8763	0,3523	54
olive	Agro-Industry	peel	77586,8	0,3877	0,0000	12,3519	0,3504	55
peach	Agro-Industry	peel	1217,7	0,3617	1,8484	11,5894	0,3468	56
oat	Agro-Industry	bran	27129,4	0,2464	3,2347	10,6745	0,3418	57
grapefruit	Agro-Industry	pulp	2153,7	0,3375	0,6931	11,1181	0,3265	58
almond	Agro-Industry	shell	47489,0	0,5547	3,8451	9,4261	0,3133	59
rye	Agro-Industry	bran	21095,2	0,2311	4,3944	8,3385	0,3032	60
cherry	Field	pruning	172092,9	0,3949	3,8451	8,7010	0,3006	61
apple	Agro-Industry	seed	576,7	0,2133	4,8283	7,4356	0,2907	62
garlic	Agro-Industry	straw, peel	1155,8	0,3904	1,8484	9,1495	0,2876	63
spinach	Agro-Industry	leave, stem, curd	1409,8	0,2697	4,4260	7,6368	0,2874	64
quince	Agro-Industry	pulp	782,9	0,3626	2,7726	8,6921	0,2870	65
peach	Field	pruning	100603,4	0,2680	4,3944	7,2508	0,2792	66
wheat	Field	straw	2257955,2	0,1994	4,0665	5,6930	0,2786	67
eggplant	Agro-Industry	peel	2524,7	0,2700	3,8451	7,2508	0,2708	68
rice	Field	straw	460981,2	0,7005	1,9183	8,4885	0,2677	69
eggplant	Agro-Industry	pulp	725,0	0,2682	3,2958	7,2508	0,2634	70
rice	Agro-Industry	husk	120846,5	0,7710	3,0212	7,9100	0,2622	71
maize	Field	stalk	564688,4	0,3556	2,7726	6,8622	0,2495	72
loquat	Agro-Industry	pulp	93,0	0,2715	2,7726	6,8622	0,2483	73
watermelon	Agro-Industry	flesh	50226,7	0,7551	0,0000	8,2346	0,2442	74
nectarine	Agro-Industry	seed	417,0	0,8337	0,0000	8,2346	0,2422	75
orange	Agro-Industry	seed	3736,8	0,2404	4,3944	5,2129	0,2399	76
banana	Field	stem, leave	136992,9	0,6850	2,1972	7,2508	0,2389	77
walnut	Field	pruning	46900,6	0,3512	4,3944	5,2129	0,2365	78
plum	Agro-Industry	seed	1096,1	0,2963	5,0169	4,2572	0,2330	79
bitter melon	Agro-Industry	seed	0,1	0,3566	2,1972	6,5258	0,2317	80
hazelnut	Agro-Industry	shell	241030,8	0,2654	1,8484	6,0997	0,2232	81
barley	Agro-Industry	husk	1250543,8	0,2144	0,0000	5,4897	0,2140	82
watermelon	Agro-Industry	seed	1571,0	0,7430	5,5452	2,7449	0,2093	83
maize	Agro-Industry	cob	1893527,3	0,4042	0,0000	4,5748	0,2070	84
parsley	Agro-Industry	leave, stem, curd	463,0	0,4510	4,3944	3,6254	0,2067	85
melon	Agro-Industry	peel	12277,1	0,2924	2,7726	4,5748	0,2017	86
potato	Field	tuber	338880,3	0,1374	2,0794	4,5748	0,2012	87
sunflower	Agro-Industry	shell	204755,2	0,3408	2,7726	4,5748	0,2007	88
peach	Agro-Industry	pulp	5326,1	0,3214	2,7726	4,5748	0,2006	89
apricot	Agro-Industry	pulp	1864,7	0,3871	2,7465	4,7130	0,2003	90
apricot	Agro-Industry	peel	1604,4	0,3920	2,7726	4,5748	0,1979	91
bitter melon	Agro-Industry	peel	0,1	0,4301	2,7726	4,5748	0,1964	92
tangarine	Agro-Industry	peel	2346,8	0,4485	2,7726	4,5748	0,1957	93
beetroot	Field	tuber	749,8	0,4682	2,7726	4,5748	0,1950	94
lentil	Agro-Industry	seed, hull	13559,1	0,3557	0,0000	5,4897	0,1938	95
beetroot	Field	vine	418,3	0,5331	2,7726	4,5748	0,1925	96
celery	Agro-Industry	leave, stem, curd	10,8	0,3713	3,2189	3,7178	0,1905	97
almond	Field	pruning	71006,4	0,6400	4,3944	2,9003	0,1902	98
potato	Field	vine	190076,3	0,2463	3,2347	3,0498	0,1866	99
sweet potato	Agro-Industry	peel	87,9	0,7499	2,7726	4,5748	0,1848	100
pomegranate	Field	pruning	42004,8	0,5318	2,0794	4,5748	0,1835	101
lettuce	Agro-Industry	leave, stem, curd	1573,5	0,2065	2,1972	3,6254	0,1817	102

jujube	Field	pruning	230,5	0,8586	2,7726	4,5748	0,1811	103
jujube	Agro-Industry	pulp	4,8	0,9021	2,7726	4,5748	0,1797	104
sweet potato	Field	tuber	986,0	0,6753	2,0794	4,5748	0,1778	105
pea	Agro-Industry	shell	665,4	0,3412	0,0000	4,5748	0,1761	106
artichoke	Agro-Industry	leave, stem, curd	490,2	0,2820	2,7726	2,2874	0,1672	107
wheat	Agro-Industry	husk	1738766,5	0,0831	0,0000	0,0000	0,1668	108
pistachio	Agro-Industry	shell	45874,4	0,6343	0,6931	4,5748	0,1666	109
watermelon	Agro-Industry	peel	27971,0	0,7599	0,0000	4,5748	0,1585	110
plum	Agro-Industry	pulp	1951,4	0,2887	2,7726	1,3724	0,1575	111
mint	Agro-Industry	leave, stem, curd	96,5	0,4993	2,7726	2,2874	0,1572	112
apple	Field	pruning	138820,0	0,1910	2,7726	0,4020	0,1560	113
cabbage	Agro-Industry	leave, stem, curd	3455,8	0,6938	1,6479	3,6254	0,1533	114
barley	Agro-Industry	bran	1480471,2	0,2249	0,0000	0,0000	0,1527	115
sweet potato	Field	vine	552,2	0,7227	2,7726	2,2874	0,1472	116
barley	Agro-Industry	grain	23486,1	0,3456	2,7726	0,0000	0,1463	117
barley	Field	stalk	1099561,7	0,1578	0,0000	0,0000	0,1458	118
chick pea	Field	stem, leave	990239,1	0,1144	0,0000	0,0000	0,1456	119
kiwi	Field	pruning	4750,9	0,6523	2,7726	1,3724	0,1401	120
barley	Field	straw	801184,2	0,1553	0,0000	0,0000	0,1395	121
chick pea	Field	straw	523046,6	0,1167	0,0000	0,0000	0,1373	122
oleaster	Field	pruning	849,1	0,1172	0,0000	0,0000	0,1335	123
carrot	Field	tuber	42824,4	0,2038	0,0000	0,9150	0,1329	124
hazelnut	Field	pruning	546933,4	0,2071	0,0000	0,0000	0,1324	125
red radish	Field	tuber	11697,3	0,1363	0,0000	0,0000	0,1324	126
citrus	Agro-Industry	seed	10,6	0,2652	0,6931	0,9150	0,1317	127
horseradish	Field	tuber	1147,6	0,1545	0,0000	0,0000	0,1313	128
cornelian cherry	Field	pruning	2231,1	0,1567	0,0000	0,0000	0,1312	129
rye	Field	straw	49506,8	0,1715	0,0000	0,0000	0,1304	130
orange	Field	pruning	737457,2	0,2998	0,0000	0,0000	0,1303	131
sesame	Field	trash	3163,0	0,1718	0,0000	0,0000	0,1303	132
loquat	Field	pruning	1437,9	0,1837	0,0000	0,0000	0,1296	133
plum	Field	pruning	54863,7	0,1899	0,0000	0,0000	0,1293	134
fig	Field	pruning	46227,3	0,1921	0,0000	0,0000	0,1291	135
grapefruit	Field	pruning	11266,6	0,1970	0,0000	0,0000	0,1288	136
salep	Field	tuber	8,5	0,2025	0,0000	0,0000	0,1284	137
sugar beet	Field	leave	460875,0	0,2581	0,0000	0,0000	0,1283	138
sunflower	Field	stalk	885172,9	0,3957	0,0000	0,0000	0,1281	139
tomato	Field	stem, leave	171192,7	0,2302	0,0000	0,0000	0,1274	140
lentil	Field	stem, leave	465928,9	0,2768	0,0000	0,0000	0,1273	141
millet	Field	straw	1607,3	0,2457	0,0000	0,0000	0,1259	142
red radish	Field	vine	6541,9	0,2472	0,0000	0,0000	0,1258	143
oat	Agro-Industry	husk	51710,3	0,2514	0,0000	0,0000	0,1256	144
oat	Field	straw	41186,7	0,2557	0,0000	0,0000	0,1253	145
chick pea	Agro-Industry	seed, hull	21227,3	0,2560	0,0000	0,0000	0,1253	146
horseradish	Field	vine	641,9	0,2589	0,0000	0,0000	0,1251	147
oleaster	Agro-Industry	pulp	18,1	0,2634	0,0000	0,0000	0,1248	148
pear	Field	pruning	63853,1	0,2669	0,0000	0,0000	0,1247	149
cornelian cherry	Agro-Industry	pulp	15,9	0,2660	0,0000	0,0000	0,1246	150
sour cherry	Field	pruning	59657,2	0,2694	0,0000	0,0000	0,1245	151
melon	Agro-Industry	flesh	20749,9	0,2768	0,0000	0,0000	0,1240	152
pear	Agro-Industry	peel	459,8	0,2776	0,0000	0,0000	0,1239	153
sugar beet seed	Field	seed	40,6	0,2832	0,0000	0,0000	0,1236	154
maize	Agro-Industry	husk	394343,4	0,3292	0,0000	0,0000	0,1233	155
locust bean	Field	pruning	1690,9	0,2890	0,0000	0,0000	0,1233	156
carrot	Field	vine	24088,0	0,2897	0,0000	0,0000	0,1232	157

salep	Field	vine	4,7	0,2910	0,0000	0,0000	0,1231	158
tobacco	Field	stalk, stem	21154,2	0,2916	0,0000	0,0000	0,1231	159
pear	Agro-Industry	pulp	2527,6	0,2916	0,0000	0,0000	0,1231	160
bean	Agro-Industry	shell	23026,2	0,2951	0,0000	0,0000	0,1229	161
pear	Agro-Industry	seed	276,1	0,2952	0,0000	0,0000	0,1229	162
loquat	Agro-Industry	seed	75,8	0,3161	0,0000	0,0000	0,1216	163
broad bean	Agro-Industry	shell	259,8	0,3173	0,0000	0,0000	0,1215	164
quince	Field	pruning	14737,5	0,3211	0,0000	0,0000	0,1213	165
chard	Agro-Industry	leave, stem, curd	43,3	0,3215	0,0000	0,0000	0,1213	166
sugar beet	Agro-Industry	pulp	161595,9	0,3370	0,0000	0,0000	0,1209	167
plum	Agro-Industry	peel	586,4	0,3332	0,0000	0,0000	0,1206	168
grapefruit	Agro-Industry	seed	723,4	0,3370	0,0000	0,0000	0,1203	169
locust bean	Agro-Industry	sees	97,7	0,3394	0,0000	0,0000	0,1202	170
cow pea	Agro-Industry	shell	718,5	0,3403	0,0000	0,0000	0,1201	171
locust bean	Agro-Industry	pulp	881,4	0,3424	0,0000	0,0000	0,1200	172
white radish	Field	tuber	323,3	0,3439	0,0000	0,0000	0,1199	173
bitter melon	Agro-Industry	pulp	1,0	0,3479	0,0000	0,0000	0,1197	174
sorghum	Field	stalk	40,1	0,6526	2,0794	0,0000	0,1196	175
barley	Agro-Industry	bagasse	6232,4	0,3488	0,0000	0,0000	0,1196	176
quince	Agro-Industry	peel	142,5	0,3509	0,0000	0,0000	0,1195	177
groundnut	Field	straw	209147,3	0,3740	0,0000	0,0000	0,1189	178
leek	Agro-Industry	stem	6860,0	0,3646	0,0000	0,0000	0,1187	179
apricot	Field	pruning	498152,4	0,4329	0,0000	0,0000	0,1185	180
cauliflower	Agro-Industry	leave, stem, curd	1536,5	0,3748	0,0000	0,0000	0,1180	181
tangarine	Field	pruning	227825,4	0,3921	0,0000	0,0000	0,1180	182
white radish	Field	vine	182,0	0,3999	0,0000	0,0000	0,1165	183
groundnut	Agro-Industry	shell	35395,2	0,4109	0,0000	0,0000	0,1159	184
tangarine	Agro-Industry	seed	1537,3	0,4409	0,0000	0,0000	0,1140	185
tangarine	Agro-Industry	pulp	4649,3	0,4439	0,0000	0,0000	0,1138	186
sugar cane	Field	top, leave	3,8	0,4452	0,0000	0,0000	0,1137	187
lemon	Field	pruning	137096,1	0,4649	0,0000	0,0000	0,1129	188
lemon	Agro-Industry	seed	3998,7	0,4987	0,0000	0,0000	0,1104	189
lemon	Agro-Industry	pulp	11947,1	0,5003	0,0000	0,0000	0,1103	190
sugar cane	Agro-Industry	pulp	4,7	0,5204	0,0000	0,0000	0,1090	191
paprika	Agro-Industry	peel, seed	6839,6	0,5603	0,0000	0,0000	0,1065	192
cabbage	Field	foliage, stem	148413,2	0,6188	0,0000	0,0000	0,1034	193
rape	Field	stalk	13628,0	0,6705	0,0000	0,0000	0,0996	194
turnip	Field	tuber	156,0	0,6733	0,0000	0,0000	0,0994	195
celeriac	Field	tuber	1404,1	0,6734	0,0000	0,0000	0,0994	196
pistachio	Field	pruning	105105,3	0,6799	0,0000	0,0000	0,0993	197
soya bean	Field	stem, leave	98668,6	0,6802	0,0000	0,0000	0,0992	198
soya bean	Agro-Industry	shell	8366,2	0,6780	0,0000	0,0000	0,0991	199
purslane	Agro-Industry	leave, stem, curd	40,8	0,6797	0,0000	0,0000	0,0990	200
soya bean	Agro-Industry	cake	4834,4	0,6806	0,0000	0,0000	0,0989	201
jerusalem artichoke	Field	tuber	56,9	0,6927	0,0000	0,0000	0,0981	202
kiwi	Agro-Industry	peel	139,2	0,6980	0,0000	0,0000	0,0978	203
medlar	Field	pruning	479,6	0,6986	0,0000	0,0000	0,0978	204
turnip	Field	vine	85,9	0,7029	0,0000	0,0000	0,0975	205
kiwi	Agro-Industry	pulp	277,2	0,7158	0,0000	0,0000	0,0967	206
jerusalem artichoke	Field	vine	31,8	0,7170	0,0000	0,0000	0,0966	207
medlar	Agro-Industry	pulp	231,6	0,7181	0,0000	0,0000	0,0965	208
soya bean	Field	straw	125110,0	0,7269	0,0000	0,0000	0,0964	209
mulberry	Agro-Industry	pulp	346,4	0,7214	0,0000	0,0000	0,0963	210
medlar	Agro-Industry	peel	22,2	0,7232	0,0000	0,0000	0,0962	211
celeriac	Field	vine	773,6	0,7321	0,0000	0,0000	0,0956	212

cress	Agro-Industry	leave, stem, curd	36,9	0,7590	0,0000	0,0000	0,0939	213
medlar	Agro-Industry	seed	13,7	0,7693	0,0000	0,0000	0,0932	214
dill	Agro-Industry	leave, stem, curd	36,6	0,7754	0,0000	0,0000	0,0928	215
persimmon	Field	pruning	5026,5	0,7834	0,0000	0,0000	0,0923	216
persimmon	Agro-Industry	seed	117,8	0,7973	0,0000	0,0000	0,0914	217
turnip	Agro-Industry	pulp	11,9	0,8042	0,0000	0,0000	0,0910	218
nectarine	Agro-Industry	pulp	1000,9	0,8099	0,0000	0,0000	0,0906	219
nectarine	Field	pruning	21455,9	0,8182	0,0000	0,0000	0,0901	220
persimmon	Agro-Industry	pulp	260,7	0,8192	0,0000	0,0000	0,0900	221
nectarine	Agro-Industry	peel	222,8	0,8248	0,0000	0,0000	0,0896	222
rocket	Agro-Industry	leave, stem, curd	82,1	1,1066	0,0000	0,0000	0,0709	223

E. SAMPLE FROM SCENARIO-BASED I-O ANALYSIS DATA

Extract	Scenario Label	Total Demand Shock	Food Share	Cosmetics Share	Pharm aShare	Food Revenue	Cosmetics Revenue	Pharma Revenue	Food Output Effect	Food VA Effect	Food Employment Effect	Cosmetics Output Effect	Cosmetics VA Effect	Cosmetics Employment Effect	Pharma Output Effect	Pharma VA Effect	Pharma Employment Effect
Bulk extract	Medium	77582669,6	0	0	1	0,0	0,0	77582669,6	0,0	0,0	0	0,0	0,0	0	124,3	50,8	895201
Bulk extract	Medium	77582669,6	0	0,1	0,9	0,0	7758267,0	69824402,6	0,0	0,0	0	12,1	3,9	36219	111,9	45,7	805681
Bulk extract	Medium	77582669,6	0	0,2	0,8	0,0	15516533,9	62066135,6	0,0	0,0	0	24,1	7,8	72439	99,5	40,6	716161
Bulk extract	Medium	77582669,6	0	0,3	0,7	0,0	23274800,9	54307868,7	0,0	0,0	0	36,2	11,7	108658	87,0	35,5	626641
Bulk extract	Medium	77582669,6	0	0,4	0,6	0,0	31033067,8	46549601,7	0,0	0,0	0	48,3	15,6	144877	74,6	30,5	537121
Bulk extract	Medium	77582669,6	0	0,5	0,5	0,0	38791334,8	38791334,8	0,0	0,0	0	60,4	19,6	181096	62,2	25,4	447601
Bulk extract	Medium	77582669,6	0	0,6	0,4	0,0	46549601,7	31033067,8	0,0	0,0	0	72,4	23,5	217316	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0	0,7	0,3	0,0	54307868,7	23274800,9	0,0	0,0	0	84,5	27,4	253535	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0	0,8	0,2	0,0	62066135,6	15516533,9	0,0	0,0	0	96,6	31,3	289754	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0	0,9	0,1	0,0	69824402,6	7758267,0	0,0	0,0	0	108,7	35,2	325974	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0	1	0	0,0	77582669,6	0,0	0,0	0,0	0	120,7	39,1	362193	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,1	0	0,9	7758267,0	0,0	69824402,6	15,1	6,0	75372	0,0	0,0	0	111,9	45,7	805681
Bulk extract	Medium	77582669,6	0,1	0,1	0,8	7758267,0	7758267,0	62066135,6	15,1	6,0	75372	12,1	3,9	36219	99,5	40,6	716161
Bulk extract	Medium	77582669,6	0,1	0,2	0,7	7758267,0	15516533,9	54307868,7	15,1	6,0	75372	24,1	7,8	72439	87,0	35,5	626641
Bulk extract	Medium	77582669,6	0,1	0,3	0,6	7758267,0	23274800,9	46549601,7	15,1	6,0	75372	36,2	11,7	108658	74,6	30,5	537121
Bulk extract	Medium	77582669,6	0,1	0,4	0,5	7758267,0	31033067,8	38791334,8	15,1	6,0	75372	48,3	15,6	144877	62,2	25,4	447601
Bulk extract	Medium	77582669,6	0,1	0,5	0,4	7758267,0	38791334,8	31033067,8	15,1	6,0	75372	60,4	19,6	181096	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0,1	0,6	0,3	7758267,0	46549601,7	23274800,9	15,1	6,0	75372	72,4	23,5	217316	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0,1	0,7	0,2	7758267,0	54307868,7	15516533,9	15,1	6,0	75372	84,5	27,4	253535	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,1	0,8	0,1	7758267,0	62066135,6	7758267,0	15,1	6,0	75372	96,6	31,3	289754	12,4	5,1	89520

Extract	Scenario Label	Total Demand Shock	Food Share	Cosmetics Share	Pharm aShare	Food Revenue	Cosmetics Revenue	Pharma Revenue	Food Output Effect	Food VA Effect	Food Employment Effect	Cosmetics Output Effect	Cosmetics VA Effect	Cosmetics Employment Effect	Pharma Output Effect	Pharma VA Effect	Pharma Employment Effect
Bulk extract	Medium	77582669,6	0,1	0,9	0	7758267,0	69824402,6	0,0	15,1	6,0	75372	108,7	35,2	325974	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,2	0	0,8	15516533,9	0,0	62066135,6	30,1	12,0	150743	0,0	0,0	0	99,5	40,6	716161
Bulk extract	Medium	77582669,6	0,2	0,1	0,7	15516533,9	7758267,0	54307868,7	30,1	12,0	150743	12,1	3,9	36219	87,0	35,5	626641
Bulk extract	Medium	77582669,6	0,2	0,2	0,6	15516533,9	15516533,9	46549601,7	30,1	12,0	150743	24,1	7,8	72439	74,6	30,5	537121
Bulk extract	Medium	77582669,6	0,2	0,3	0,5	15516533,9	23274800,9	38791334,8	30,1	12,0	150743	36,2	11,7	108658	62,2	25,4	447601
Bulk extract	Medium	77582669,6	0,2	0,4	0,4	15516533,9	31033067,8	31033067,8	30,1	12,0	150743	48,3	15,6	144877	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0,2	0,5	0,3	15516533,9	38791334,8	23274800,9	30,1	12,0	150743	60,4	19,6	181096	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0,2	0,6	0,2	15516533,9	46549601,7	15516533,9	30,1	12,0	150743	72,4	23,5	217316	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,2	0,7	0,1	15516533,9	54307868,7	7758267,0	30,1	12,0	150743	84,5	27,4	253535	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,2	0,8	0	15516533,9	62066135,6	0,0	30,1	12,0	150743	96,6	31,3	289754	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,3	0	0,7	23274800,9	0,0	54307868,7	45,2	18,0	226115	0,0	0,0	0	87,0	35,5	626641
Bulk extract	Medium	77582669,6	0,3	0,1	0,6	23274800,9	7758267,0	46549601,7	45,2	18,0	226115	12,1	3,9	36219	74,6	30,5	537121
Bulk extract	Medium	77582669,6	0,3	0,2	0,5	23274800,9	15516533,9	38791334,8	45,2	18,0	226115	24,1	7,8	72439	62,2	25,4	447601
Bulk extract	Medium	77582669,6	0,3	0,3	0,4	23274800,9	23274800,9	31033067,8	45,2	18,0	226115	36,2	11,7	108658	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0,3	0,4	0,3	23274800,9	31033067,8	23274800,9	45,2	18,0	226115	48,3	15,6	144877	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0,3	0,5	0,2	23274800,9	38791334,8	15516533,9	45,2	18,0	226115	60,4	19,6	181096	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,3	0,6	0,1	23274800,9	46549601,7	7758267,0	45,2	18,0	226115	72,4	23,5	217316	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,3	0,7	0	23274800,9	54307868,7	0,0	45,2	18,0	226115	84,5	27,4	253535	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,4	0	0,6	31033067,8	0,0	46549601,7	60,3	24,0	301487	0,0	0,0	0	74,6	30,5	537121
Bulk extract	Medium	77582669,6	0,4	0,1	0,5	31033067,8	7758267,0	38791334,8	60,3	24,0	301487	12,1	3,9	36219	62,2	25,4	447601
Bulk extract	Medium	77582669,6	0,4	0,2	0,4	31033067,8	15516533,9	31033067,8	60,3	24,0	301487	24,1	7,8	72439	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0,4	0,3	0,3	31033067,8	23274800,9	23274800,9	60,3	24,0	301487	36,2	11,7	108658	37,3	15,2	268560

Extract	Scenario Label	Total Demand Shock	Food Share	Cosmetics Share	Pharm aShare	Food Revenue	Cosmetics Revenue	Pharma Revenue	Food Output Effect	Food VA Effect	Food Employment Effect	Cosmetics Output Effect	Cosmetics VA Effect	Cosmetics Employment Effect	Pharma Output Effect	Pharma VA Effect	Pharma Employment Effect
Bulk extract	Medium	77582669,6	0,4	0,4	0,2	31033067,8	31033067,8	15516533,9	60,3	24,0	301487	48,3	15,6	144877	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,4	0,5	0,1	31033067,8	38791334,8	7758267,0	60,3	24,0	301487	60,4	19,6	181096	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,4	0,6	0	31033067,8	46549601,7	0,0	60,3	24,0	301487	72,4	23,5	217316	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,5	0	0,5	38791334,8	0,0	38791334,8	75,4	29,9	376858	0,0	0,0	0	62,2	25,4	447601
Bulk extract	Medium	77582669,6	0,5	0,1	0,4	38791334,8	7758267,0	31033067,8	75,4	29,9	376858	12,1	3,9	36219	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0,5	0,2	0,3	38791334,8	15516533,9	23274800,9	75,4	29,9	376858	24,1	7,8	72439	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0,5	0,3	0,2	38791334,8	23274800,9	15516533,9	75,4	29,9	376858	36,2	11,7	108658	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,5	0,4	0,1	38791334,8	31033067,8	7758267,0	75,4	29,9	376858	48,3	15,6	144877	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,5	0,5	0	38791334,8	38791334,8	0,0	75,4	29,9	376858	60,4	19,6	181096	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,6	0	0,4	46549601,7	0,0	31033067,8	90,4	35,9	452230	0,0	0,0	0	49,7	20,3	358081
Bulk extract	Medium	77582669,6	0,6	0,1	0,3	46549601,7	7758267,0	23274800,9	90,4	35,9	452230	12,1	3,9	36219	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0,6	0,2	0,2	46549601,7	15516533,9	15516533,9	90,4	35,9	452230	24,1	7,8	72439	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,6	0,3	0,1	46549601,7	23274800,9	7758267,0	90,4	35,9	452230	36,2	11,7	108658	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,6	0,4	0	46549601,7	31033067,8	0,0	90,4	35,9	452230	48,3	15,6	144877	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,7	0	0,3	54307868,7	0,0	23274800,9	105,5	41,9	527602	0,0	0,0	0	37,3	15,2	268560
Bulk extract	Medium	77582669,6	0,7	0,1	0,2	54307868,7	7758267,0	15516533,9	105,5	41,9	527602	12,1	3,9	36219	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,7	0,2	0,1	54307868,7	15516533,9	7758267,0	105,5	41,9	527602	24,1	7,8	72439	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,7	0,3	0	54307868,7	23274800,9	0,0	105,5	41,9	527602	36,2	11,7	108658	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,8	0	0,2	62066135,6	0,0	15516533,9	120,6	47,9	602973	0,0	0,0	0	24,9	10,2	179040
Bulk extract	Medium	77582669,6	0,8	0,1	0,1	62066135,6	7758267,0	7758267,0	120,6	47,9	602973	12,1	3,9	36219	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,8	0,2	0	62066135,6	15516533,9	0,0	120,6	47,9	602973	24,1	7,8	72439	0,0	0,0	0
Bulk extract	Medium	77582669,6	0,9	0	0,1	69824402,6	0,0	7758267,0	135,7	53,9	678345	0,0	0,0	0	12,4	5,1	89520
Bulk extract	Medium	77582669,6	0,9	0,1	0	69824402,6	7758267,0	0,0	135,7	53,9	678345	12,1	3,9	36219	0,0	0,0	0
Bulk extract	Medium	77582669,6	1	0	0	77582669,6	0,0	0,0	150,7	59,9	753717	0,0	0,0	0	0,0	0,0	0

F. TURKISH SUMMARY / TÜRKÇE ÖZET

Artan dünya nüfusu ve yaşam kalitesine yönelik beklentiler, gıda ve hammadde üretimi üzerindeki baskıyı artırmakta ve bu durum tarımsal faaliyetlerin hem hacmini hem de çeşitliliğini hızla genişletmektedir (Bozerup, 1975). Tarımsal üretim süreçleri; ürün yetiştiriciliği, hasat, işleme ve pazarlama gibi temel aşamaları kapsarken, bu süreçlerin doğal bir çıktısı olarak önemli miktarda yan ürün ve atık oluşmaktadır. Ekonomik değeri düşük olduğu varsayılan ve genellikle ikincil öneme sahip bu çıktılar, toplama, taşıma, depolama ve işleme maliyetlerine rağmen "tarımsal atık" olarak sınıflandırılmaktadır (Maji vd., 2020).

Son yüzyılda özellikle Çin, Hindistan ve Afrika'daki hızlı nüfus artışı ve tarımsal büyüme ile birlikte tarımsal atık miktarlarında küresel ölçekte ciddi artış yaşanmıştır (Koul vd., 2021). Gelişmekte olan ülkelerde tarımın genişlemesi devam ettikçe, bu artışın ivme kazanması beklenmektedir. Bu durum, tarımsal atıkların geri kazanımı, geri dönüşümü ve yeniden kullanımı gibi döngüsel ekonomi uygulamalarının önemini artırmakta; etkili bir tarımsal atık yönetimi için atıkların kaynağı, miktarı ve bileşimi üzerine yapılacak analizlerin stratejik bir gereklilik olduğunu göstermektedir.

Türkiye, sahip olduğu agroekolojik çeşitlilik, farklı iklim kuşakları ve zengin bitkisel üretim deseni ile dünyanın önde gelen tarım ülkelerinden biridir (Sarı, 2022). Bu üretim potansiyeli yalnızca birincil ürünler açısından değil, aynı zamanda saha ve agro-endüstriyel atıklar bakımından da yüksek bir atık hacmi yaratmaktadır. Tarımsal üretim süreçlerinden kaynaklanan bu atıklar uzun yıllar boyunca düşük değerli yan ürünler olarak değerlendirilmiş olsa da; biyoekonomi, biyokimya ve yeşil dönüşüm politikalarının güçlenmesiyle birlikte yüksek katma değerli girdilere dönüştürülme potansiyeli taşıdığı daha net anlaşılmıştır (Eraktan, 2011; Sarı, 2022). Özellikle gıda, kozmetik, ilaç ve biyoteknoloji gibi sektörlerde artan doğal kaynak ihtiyacı, tarımsal atıkların biyoaktif bileşen, biyoyakıt, kompost, yem veya biyomalzeme gibi alanlarda yeniden değerlendirilmesini mümkün kılmaktadır. Bu yönüyle tarımsal atıklar yalnızca çevresel bir yük değil, aynı zamanda stratejik bir ekonomik kaynak olarak ele alınmalıdır. Nitekim Türkiye'de yapılan çalışmalar, il, bölge ve ulusal düzeyde farklı ürünlere ait atıkların geri dönüşüm potansiyelini ortaya koymakta; enerji üretimi başta olmak üzere çeşitli alanlarda kullanım önerileri sunmaktadır. Özellikle biyoyakıt ve biyokütle bazlı katı yakıt üretimine odaklanan bu çalışmalar, genellikle Türkiye'nin yüksek enerji ithalatı bağımlılığı ve yenilenebilir enerji hedefleri bağlamında şekillenmiştir (Adıgüzel, 2013; Melikoğlu, 2011; Özütemiz, 2017; Fidan ve Alkan, 2014; Çolakoğlu, 2018). Ancak bu yaklaşım, tarımsal atıkların sahip olduğu yüksek katma değerli biyokimyasal içeriklerin yeterince değerlendirilememesi gibi önemli bir sınırlılığa sahiptir.

Her ne kadar biyoaktif bileşenler sentetik yollarla da üretilebilse de, bu üretim yöntemlerinin uzun vadeli sağlık ve çevresel etkilerine dair çeşitli endişeler bulunmaktadır. Yapay antioksidanlar, sentetik gıda katkı maddeleri ve bazı farmasötik bileşiklerin potansiyel kanserojen etkileri literatürde sıkça tartışılmakta; reaktif oksijen türlerinin artışı gibi metabolik bozukluklarla ilişkilendirilmektedir (Nieto vd., 2023; Verep vd., 2023). Ayrıca, endüstriyel uygulamalarda kullanılan ağır metal bazlı katkı maddelerinin toksik etkileri de insan ve çevre sağlığı açısından ciddi riskler barındırmaktadır (Ong vd., 2021). Bu nedenlerle günümüzde birçok sektör sentetik bileşenlerden uzaklaşmakta ve bunun yerine bitkisel, mikrobiyal ve özellikle tarımsal atıklardan elde edilen doğal biyoaktif bileşenlere yönelmektedir. Fonksiyonel gıdalar, doğal kozmetikler ve bitkisel ilaçlar gibi ürünlerin artan popülaritesi bu dönüşümü daha da hızlandırmaktadır.

Bu noktada, doğal bileşenlerin etkin, seçici ve çevre dostu bir biçimde elde edilmesini sağlayan süperkritik akışkan ekstraksiyonu (SFE) gibi teknolojiler sürdürülebilir üretim stratejilerinin vazgeçilmez bir parçası haline gelmiştir. Genellikle karbondioksit (CO_2) gibi çevreye zarar vermeyen çözücülerle gerçekleştirilen SFE; düşük sıcaklıklarda çalışması, yüksek seçicilik kapasitesi ve solvent kalıntısı bırakmaması gibi avantajlarıyla özellikle ısıya duyarlı biyoaktif bileşenlerin ekstraksiyonunda geleneksel yöntemlere kıyasla üstün performans sunmaktadır (Sapkale vd., 2010; Ahmad vd., 2019; Fretias vd., 2021; Rifna vd., 2021; Jha ve Sit, 2021). Bu nedenle, SFE yöntemi ile tarımsal atıklardan değerli biyoaktif bileşenlerin elde edilmesi hem çevresel sürdürülebilirliğe hem de yüksek katma değerli üretim stratejilerine hizmet eden bütüncül bir yaklaşım olarak öne çıkmaktadır (Santana vd., 2024).

Bu çalışma, Türkiye'deki tarımsal üretimden kaynaklanan bitkisel atıkların, SFE yöntemiyle yüksek katma değerli biyoaktif bileşenlere dönüştürülme potansiyelini ve bu dönüşümün makroekonomik etkilerini analiz etmeyi amaçlamaktadır. Bu çalışmanın temel katkısı, tarımsal atıkların sadece çevresel bir sorun veya enerji kaynağı olarak değil, yüksek katma değerli biyoaktif bileşenlerin sürdürülebilir üretiminde stratejik bir girdi olarak ele alınmasını sağlayan bütüncül bir değerlendirme çerçevesi sunmasıdır. Literatürde çoğunlukla teknik verimlilik, proses optimizasyonu veya belirli ürünler özelinde yapılan sınırlı kapsamlı analizlerin ötesine geçen bu çalışma, atık–ürün–bileşen zincirini sistematik biçimde modelleyerek, çok kriterli karar verme (ÇKKV) yöntemleriyle öncelikli atık kaynaklarını tanımlamış, ardından bu kaynakların ülke ekonomisine olası katkılarını senaryo bazlı Girdi-Çıktı (G-Ç) analizi ile ortaya koymuştur. Tarım, gıda, kozmetik ve ilaç sektörlerini kesen bu entegre yaklaşım; döngüsel ekonomi, yerli üretim ve istihdam artışı gibi ulusal kalkınma hedefleriyle doğrudan örtüşen özgün bulgular sunmakta, politika yapıcılara yön verici nitelikte bilimsel bir temel oluşturmaktadır.

Çalışmanın ilk aşamasında, Türkiye'de üretimi yapılan 132 farklı tarımsal ürüne ait saha ve agro-endüstriyel kaynaklı atıkların, ürün–atık bazında nicel olarak belirlenmesi hedeflenmiştir. Atık miktarlarının hesaplanmasında; ürünlerin yıllık üretim verileri ile ürün-atık oranı (RPR), nem oranı, sanayi işleme oranı, sanayi atık oranı ve toplanabilirlik katsayısı gibi parametreler birlikte kullanılmıştır. Bu parametrelerin sabit kabul edilmesi, doğası gereği deterministik bir hesaplama yaklaşımını beraberinde getirir; ancak söz konusu parametreler literatürde çoğu zaman aralıklar hâlinde raporlanmakta ve bu durum, tahminlerde belirsizlik doğurmaktadır. Dolayısıyla, belirsizlikleri hesaba katabilen bir yaklaşım kullanılması, daha gerçekçi ve güvenilir sonuçlara ulaşmayı mümkün kılar.

Bu amaçla, son yıllarda tarımsal atık miktarlarının tahmininde giderek daha çok başvurulan Monte Carlo simülasyonu tercih edilmiştir. Monte Carlo yöntemi, çok sayıda rasgele örneklemeye dayalı simülasyonlar yürüterek, belirsizlik altındaki giriş değişkenlerinin çıktılar üzerindeki etkilerini olasılık dağılımları üzerinden modeller. Böylece deterministik olmayan, çok parametreli sistemlerdeki varyasyonu görünür kılar ve karar vericiye yalnızca tek bir nokta tahmini değil, güven aralıkları ile birlikte bir sonuç uzayı sunar.

Literatürde bu yaklaşıma ilişkin çeşitli örnekler bulunmaktadır. Örneğin Song vd. (2014), Çin'e ait 2123 farklı RPR verisini kullanarak ürün bazında parametrik dağılımlar kurmuş; normal, log-normal ve gamma dağılımları üzerinden 2000 iterasyon ile Monte Carlo simülasyonu yürütmüştür. Lyakurwa (2016), farklı ürün grupları için RPR verilerini dağılımlar altında tanımlayarak yine 2000 iterasyon ile atık miktarlarını tahmin etmiş ve sonuçları histogram temelli dağılım analizleriyle sunmuştur. Maqhuzu vd. (2017) ise Zimbabwe örneğinde tarımsal üretim ve hayvansal atık kökenli biyoyakıt potansiyelini 100.000 iterasyon ile simüle etmiştir. Bu çalışmaların ortak noktası, belirsizliği genellikle tek bir parametre (çoğunlukla RPR) üzerinde ele almalarıdır; diğer kritik parametreler çoğu kez sabit bırakılmış veya atık miktarı hesaplamalarına dahil edilmemiştir. Bu tez çalışması ise literatürdeki bu çerçeveyi genişleterek yalnızca RPR değil, nem oranı, sanayi işleme oranı, sanayi atık oranı ve toplanabilirlik katsayısı dâhil tüm temel parametreleri belirsizlik altında modellemiş, böylelikle sistemin tamamına yayılan değişkenliği hesaba katmıştır.

Veri seti, TÜİK Bitkisel Üretim İstatistikleri veri tabanından elde edilen 2004–2024 dönemine ait 21 yıllık zaman serisini kapsamaktadır. Her bir ürün için bu dönem aralığında ortalama ve standart sapma değerleri hesaplanmış; serilerin dağılım özellikleri Shapiro–Wilk, Anderson–Darling ve Kolmogorov–Smirnov gibi normallik testleriyle değerlendirilmiştir. Veri yapısının parametrik varsayımları karşılamadığı durumlarda (özellikle gözlem sayısı sınırlı olan serilerde) ampirik dağılımlar kullanılarak belirsizlikler doğrudan veriden modellenmiştir. Ürün-atık ilişkisinde yer alan RPR, nem, sanayi işleme oranı ve sanayi atık oranı gibi parametreler için Türkiye bağlamında doğrudan, sürekli ve tutarlı idari veri bulunmadığından; bu parametreler literatür çalışmaları, sanayi raporları ve fizibilite dokümanları taranarak Türkiye özelinde derlenmiştir. Söz konusu kaynaklarda parametreler çoğunlukla minimum–maksimum aralıklarıyla verildiği için, aralık verilerini temsil eden uniform ve (uygun olduğu hâllerde) beta dağılımları varsayılmış; temel uygunluk kontrolleri yapıldıktan sonra simülasyona dahil edilmiştir. Toplanabilirlik katsayısı, literatürde yaygın biçimde sabit katsayı olarak kullanıldığından, bu çalışmada da sabit bir parametre olarak ele alınmıştır.

Simülasyon yapısı şu şekilde kurgulanmıştır: Her bir ürün–atık çifti için belirlenen olasılık dağılımlarından rassal örneklemeler alınmış; böylece teorik atık, toplanabilir atık, kuru atık ve toplanabilir kuru atık metrikleri için çıktı dağılımları elde edilmiştir. Başlangıçta farklı iterasyon sayıları denenmiş; çıktıların medyan ve çeyrekler aralığındaki değişimi ile yakınsama ve kararlılık izlenmiştir. Hesaplama yükü ile çıktı kararlılığı arasında denge kuran optimum iterasyon sayısı 6.000 olarak belirlenmiş ve tüm ürün–atık kombinasyonları bu ayarla simüle edilmiştir. Her kombinasyon için minimum, medyan ve maksimum değerler raporlanmış; böylece karar vericiye hem merkezi eğilim hem de yayılım bilgisi sunulmuştur.

Elde edilen bulgular, 132 ürünün 285 ürün–atık çifti bazında; yıllık ortalama 105 milyon ton teorik atık, 70 milyon ton kuru teorik atık, 50 milyon ton toplanabilir atık ve 30 milyon ton toplanabilir kuru atık düzeyine işaret etmektedir. Saha atıkları teorik atığın yaklaşık %78'ini oluşturmaktadır; ancak lojistik kısıtlar ve dağınık oluşum nedeniyle toplanabilir atıklar içindeki payları %63'e gerilemektedir. Buna karşılık, saha atıklarının nem oranlarının görece düşük olması, kuru atık içindeki paylarını yeniden %77 seviyesine taşımakta; fakat toplanabilir kuru atık içinde pay %55'e düşmektedir. Agro-endüstriyel atıklar ise daha sistematik oluştukları ve toplama altyapısı ile entegre oldukları için toplanabilirlikte avantajlıdır; ancak çoğu zaman daha yüksek nem içerikleri nedeniyle kuru bazda görece düşük hacimler verebilmektedir.

Sonuçların dış geçerliliği, Türkiye odaklı çalışmalarla kıyaslanarak sınanmıştır. Biyokütle Enerji Potansiyel Atlası (BEPA) ve Avcıoğlu (2019), Bahadıroğlu (2022), Ünal (2007) gibi araştırmalardaki tahminlerle yapılan karşılaştırmalar, sabit katsayı yaklaşımına dayanan geleneksel metodolojilerin atık miktarlarını çoğu zaman yukarı yönlü tahmin ettiğini göstermektedir. Bu çalışmanın dağılımsal ve belirsizlik temelli çerçevesi ise daha temkinli ve bandlı çıktılar üretmiştir. Farkın yalnızca son yıllardaki üretim artışından kaynaklanmadığı; ürün desenindeki kompozisyon değişimleri ile RPR ve işleme oranı gibi parametrelerdeki varyasyonun da belirleyici olduğu görülmüştür.

Ek olarak, her ürün–atık çifti için varyasyon katsayısı (CV) hesaplanmış; böylece parametre kaynaklı belirsizliğin profili çıkarılmıştır. Bulgular, belirsizlik düzeyinin ürünler arasında heterojen olduğunu göstermektedir: Pek çok üründe baskın belirsizlik kaynağı tarımsal üretimdeki dalgalanmalar iken, bazı agro-endüstriyel atıklarda RPR veya sanayi işleme oranı parametrelerindeki belirsizlik öne çıkmaktadır. Bu ayrım, saha uygulamalarında veri iyileştirme önceliklerinin (ör. üretim istikrarı vs. proses parametrelerinin daha iyi ölçülmesi) farklı ürün grupları için değişebileceğine işaret eder.

Miktar tek başına yeterli bir gösterge olmadığından, çalışmanın ikinci aşamasında sistematik bir literatür taraması gerçekleştirilmiştir. Bu tarama, PRISMA metodolojisi çerçevesinde, 2010 yılı sonrasını kapsayacak şekilde Scopus, Web of Science, ScienceDirect, Springer Nature ve PubMed veritabanlarında yapılmıştır. İlk aşamada ulaşılan 2.530 yayın, başlık, özet ve anahtar kelime bölümleri üzerinden incelenmiş ve tarımsal ürün–atık eşleşmeleri metin madenciliği yöntemleriyle belirlenmiştir. Otomatik olarak yapılan bu eşleşmeler, doğruluğun sağlanması amacıyla manuel olarak gözden geçirilmiş; hatalı veya anlamsız eşleşmeler elenmiştir. Sonuçta doğrulanmış 790 yayın detaylı içerik analizine tabi tutulmuştur. Bu analizlerde her bir çalışmada kullanılan ekstraksiyon yöntemi, raporlanan parametreler (sıcaklık, basınç, süre, çözücü, yardımcı çözücü), elde edilen verim, ekstrakte edilen biyoaktif bileşikler ve bu bileşiklerin kullanım alanları sistematik bir şablon çerçevesinde sınıflandırılmıştır. Böylece her ürün–atık çiftinin literatürde ne düzeyde çalışıldığı ve hangi parametrelerin raporlandığı ortaya konmuştur.

Elde edilen bilgiler ışığında iki ayrı skor geliştirilmiştir. SFE Skoru, süperkritik ekstraksiyon yönteminin ne ölçüde ayrıntılı ve güvenilir biçimde raporlandığını sayısallaştırmak amacıyla tasarlanmıştır. Skorun belirlenmesinde üç kriter dikkate alınmıştır: (i) yöntemin açıkça “SFE” olarak tanımlanması, (ii) temel ekstraksiyon parametrelerinin (örneğin sıcaklık, basınç, süre) ve mümkünse diğer detayların bildirilmesi, (iii) verim bilgisinin sunulması. Bu kriterlere göre her yayın 0–4 arası puanlanmış ve ilgili ürün–atık çifti için teknik güvenilirlik düzeyi ortaya konmuştur.

Biyoaktif Skor ise, elde edilen bileşiklerin sadece kimyasal varlık olarak değil, aynı zamanda fonksiyonel ve sektörel değerleriyle birlikte değerlendirilmesini sağlamaktadır. Bu kapsamda, raporlanan bileşiklerin sınıfları (fenolikler, karotenoidler, tokoferoller, steroller vb.), işlevleri (ör. antioksidan, antimikrobiyal), sektörel uygulama alanları (gıda, kozmetik, ilaç) ve ekonomik değerleri dikkate alınarak puan ataması yapılmıştır. Yüksek Biyoaktif Skor, o atığın daha değerli ve fonksiyonel bileşikler sunduğunu göstermektedir.

Her iki skor farklı boyutları temsil ettiğinden, karşılaştırılabilir olmaları için normalize edilmiştir. Bu normalizasyon sayesinde hem sık çalışılan atıklar hem de az çalışılmış ama yüksek değerli bileşikler içeren atıklar dengeli bir şekilde aynı ölçekte değerlendirilmiştir. Sonuçta SFE Skoru ve Biyoaktif Skor, her bir ürün–atık kombinasyonunun hem teknik uygulanabilirliğini hem de biyolojik-ticari değerini temsil eden göstergeler olarak çok kriterli karar analizi sürecine dâhil edilmiştir.

Elde edilen SFE Skoru ve Biyoaktif Skor, belirsizlik modellemesinden hesaplanan toplanabilir kuru atık miktarı ve CV ile birlikte çalışmanın üçüncü aşamasında kullanılacak çok kriterli karar analizi için temel girdileri oluşturmuştur. Bu çok boyutlu veri seti, önce Analitik Hiyerarşi Süreci (AHP) ile ağırlıklandırılmış, ardından İdeal Çözüme Benzerliğe Göre Tercih Sıralama Tekniği (TOPSIS) yöntemiyle normalize edilmiş karar matrisi üzerinde ideal çözüme yakınlık katsayıları hesaplanarak ürün–atıkların önceliklendirilmesi yapılmıştır. Böylece yalnızca “ne kadar atık var?” sorusuna değil, aynı zamanda “hangi atık daha işlenebilir, literatürde daha iyi belgelenmiş ve daha yüksek biyolojik-ticari değere sahip?” sorularına da bütüncül ve kanıta dayalı bir yanıt üretilmiştir.

Literatürdeki benzer çalışmalar çoğunlukla enerji odaklı kriterler (örneğin biyoyakıt potansiyeli, enerji yoğunluğu, yanma verimliliği) üzerine yoğunlaşırken (Osei vd., 2023; Zoma ve Sawadogo, 2023), bu tezde farklı bir yaklaşım benimsenmiş ve biyoaktif bileşik üretimi perspektifi esas alınmıştır. Bu doğrultuda dört temel kriter belirlenmiştir: atık miktarı, CV, SFE Skoru ve Biyoaktif Skor.

AHP analizinde kriter ağırlıkları hesaplanmış; sonuçta Biyoaktif Skor en yüksek öneme sahip kriter olarak öne çıkmıştır. Bunu SFE Skoru takip etmiş, atık miktarı ile varyasyon katsayısı ise eşit ağırlıklarla değerlendirilmiştir. Bu dağılım, yalnızca hacimsel büyüklüğün değil, aynı zamanda literatürdeki teknik uygulanabilirlik ve biyoaktif değer unsurlarının da dikkate alınması gerektiğini göstermektedir. Ayrıca elde edilen tutarlılık oranı (CR = 0.0161) kabul edilebilir düzeydedir ve hesaplamaların güvenilirliğini teyit etmektedir.

AHP'den elde edilen ağırlıkların TOPSIS analizine entegre edilmesiyle her ürün–atık çifti normalize edilmiş karar matrisi üzerinden değerlendirilmiş ve ideal çözüme yakınlık katsayıları hesaplanmıştır. Analiz sonucunda üzüm çekirdeği ve posası, domates kabuğu, posası ve çekirdeği ile zeytin posası ve budama atıkları en yüksek önceliğe sahip kaynaklar olarak öne çıkmıştır. Bu atıkların üst sıralarda yer almasında yüksek ve sürdürülebilir üretim hacimleri, literatürde güçlü biçimde temsil edilmeleri ve zengin biyoaktif bileşik içerikleri belirleyici olmuştur.

Buna karşılık bazı saha atıkları, yüksek üretim hacimlerine rağmen literatürde yeterince çalışılmadıkları için daha alt sıralarda yer almıştır. Bu durum, yalnızca miktara dayalı sıralama yaklaşımının sınırlılığını açıkça ortaya koymaktadır. Öte yandan portakal kabuğu, balkabağı çekirdeği ve elma posası gibi bazı agro-endüstriyel atıklar, literatürde görece az çalışılmış olmalarına rağmen sahip oldukları yüksek biyoaktif bileşik potansiyeli sayesinde orta sıralarda yer almış ve dikkate değer fırsatlar sunduğu görülmüştür.

Sonuç olarak, AHP–TOPSIS analizi, tarımsal atıkların yalnızca miktarlarına göre değil; aynı zamanda işlenebilirlik, literatür desteği ve ekonomik değer kriterleri temelinde önceliklendirilmesine imkân tanımış; böylece hangi atıkların biyoaktif bileşik üretiminde stratejik olarak öne çıkarılması gerektiğine dair kapsamlı bir değerlendirme sunmuştur. Öncelikli atık grupları için üç farklı işleme kapasitesi senaryosu geliştirilmiştir: 1.000 ton/yıl pilot ölçek, 10.000 ton/yıl orta ölçek ve

30.000 ton/yıl ticari ölçek. Bu senaryolara dayalı hesaplamalar, bulk ekstrakt üretiminin yıllık 0,1–4,5 kt aralığında gerçekleşebileceğini ve 120 milyon–1,5 milyar USD arasında değişen gelir potansiyeli sunduğunu ortaya koymuştur.

Agro-endüstriyel atıklar arasında özellikle domates posası, üzüm posası ve zeytin posası yüksek hacimli üretim potansiyeli ile öne çıkmaktadır. Bununla birlikte, oleuropein, tokoferoller ve likopen gibi spesifik bileşiklerin düşük tonajlarda dahi yüz milyonlarca dolarlık ekonomik katkılar sağlayabildiği görülmüştür. Örneğin, likopenin yıllık 100–250 milyon USD, oleuropeinin yaklaşık 120 milyon USD ve hidroksitirosolün 80–130 milyon USD gelir potansiyeline sahip olduğu hesaplanmıştır. Bu sonuçlar, tarımsal atıkların yalnızca yüksek hacimli üretimler için değil, aynı zamanda düşük tonajlı fakat yüksek piyasa değerine sahip bileşikler açısından da stratejik bir kaynak sunduğunu göstermektedir.

Mikro düzeyde hesaplanan gelir tahminleri, makro düzeyde G-Ç analizi ile değerlendirilmiştir. Bu kapsamda, 2022 yılı için güncellenmiş 64 sektörlü tablo kullanılmış ve nihai talep şokları gıda, kozmetik ve ilaç sektörlerine yönlendirilmiştir. Analiz sonuçlarına göre, gıda sektörü 1.94 çıktı ve 0.77 katma değer çarpanı ile en yüksek etkiye sahiptir; her 1 milyon USD'lik talep yaklaşık 5 kişilik istihdam yaratmaktadır. Kozmetik sektörü 1.56 çıktı ve 0.50 katma değer çarpanı ile görece daha sınırlı etki göstermektedir. İlaç sektörü ise 1.60 çıktı ve 0.65 katma değer çarpanı ile yüksek teknoloji yapısını yansıtmakta; 0.0072 istihdam çarpanı sayesinde birim başına en yüksek istihdamı sağlamaktadır.

Bu çarpanlar senaryolarla birlikte değerlendirildiğinde, farklı yönlendirmelerin ekonomi üzerinde nasıl sonuçlar doğurduğu açıkça görülmektedir. Örneğin, orta ölçekli bir bulk ekstrakt üretim senaryosunda, tüm üretimin yalnızca gıda sektörüne yönlendirilmesi hâlinde yaklaşık 120 milyon USD çıktı, 39 milyon USD katma değer ve 362 bin kişilik istihdam etkisi ortaya çıkmaktadır. Buna karşılık, üretimin ilaç sektörüne yönlendirilmesi durumunda toplam çıktı 112 milyon USD, katma değer 45 milyon USD, istihdam ise 750 bin kişi seviyesine ulaşmaktadır. Bu bulgular, hangi sektöre yönlendirme yapılacağının yalnızca ekonomik büyüklük açısından değil, aynı zamanda istihdam kapasitesi ve teknoloji yoğunluğu bakımından da stratejik bir karar olduğunu göstermektedir.

Genel olarak, gıda sektörü yüksek yayılım etkisiyle kısa vadede güçlü sonuçlar üretirken; ilaç sektörü uzun vadeli teknolojik dönüşüm ve nitelikli istihdam kapasitesi açısından öne çıkmaktadır. Kozmetik sektörü ise katma değerli ihracat potansiyeliyle ara bir konumda yer almakta, özellikle marka değerinin artışıyla birlikte ekonomik getirilerinin çeşitlenebileceğini göstermektedir.

Bunun yanı sıra, spesifik bileşiklerin potansiyeli de dikkate değerdir. Likopen, oleuropein ve hidroksitirosol gibi bileşikler düşük üretim hacimlerine rağmen, özellikle ilaç ve kozmetik sektörlerindeki yüksek piyasa değerleri sayesinde ekonomiye önemli katkılar sunmaktadır. Yapılan hesaplamalara göre, likopenin yıllık 100–250 milyon USD, oleuropeinin yaklaşık 120 milyon USD ve hidroksitirosolün 80–130 milyon USD gelir potansiyeline sahip olduğu belirlenmiştir. Bu durum, yıllık yalnızca birkaç yüz tonluk üretimin dahi yüz milyonlarca dolarlık ekonomik değer yaratabileceğini ortaya koymaktadır. Dolayısıyla, düşük tonajlı spesifik bileşiklerin üretimi, stratejik ürün çeşitliliği açısından bulk ekstraktlara güçlü bir tamamlayıcı unsur oluşturmaktadır.

Bütün bu bulgular, çalışmanın önemli katkılarını ortaya koymakla birlikte, belirli sınırlılıkları da beraberinde getirmektedir. Öncelikle, atık miktarlarının hesaplanmasında kullanılan RPR, nem ve toplanabilirlik oranları farklı kaynaklarda değişkenlik göstermekte ve bu durum sonuçlara belirsizlik katmaktadır. Ayrıca, spesifik bileşiklere ilişkin verim verileri büyük ölçüde laboratuvar ölçeğinde elde edilmiş olup, pilot ve ticari ölçeklerde verim kayıpları yaşanabileceği göz ardı edilmemelidir. Çalışmada gelir potansiyelleri hesaplanmış olsa da, sermaye, enerji, işgücü ve lojistik maliyetleri kapsamlı olarak değerlendirilmemiştir. Benzer şekilde, piyasa fiyatlarındaki dalgalanmalar ve küresel talep artışları da analize doğrudan yansıtılmamıştır. Çevresel göstergeler (karbon ayak izi, sera gazı azaltımı vb.) ise bu tez kapsamında kapsam dışı bırakılmıştır.

Bu sınırlılıklar doğrultusunda gelecek araştırmalar için çeşitli alanlar öne çıkmaktadır. Öncelikle, öncelikli atıklar için pilot ölçekli SFE uygulamalarının geliştirilmesi, laboratuvar verilerinin saha koşullarıyla karşılaştırılmasına imkân tanıyacaktır. Ayrıca, sermaye ve işletme maliyetlerini içeren bütüncül maliyet analizleri, kârlılık hesaplarının daha güvenilir yapılmasına katkı sağlayacaktır. Türkiye'de tarımsal atıkların dinamik bir envanterinin oluşturulması, özellikle agro-endüstriyel atıkların sistematik biçimde kapsama alınması ve bölgesel farklılıkların parametre bazında entegrasyonu, daha gerçekçi projeksiyonlara olanak sağlayacaktır. Bu doğrultuda BEPA gibi mevcut veri tabanlarının güncellenmesi ve biyoekonomi perspektifiyle yeniden yapılandırılması kritik önem taşımaktadır.

Düzenleyici açıdan, mevcut mevzuat (ör. 5996 sayılı Kanun, Takviye Edici Gıdalar Yönetmeliği, Sağlık Beyanı Yönetmeliği, Geleneksel Bitkisel Tıbbi Ürünler Ruhsatlandırma Yönetmeliği) temel bir çerçeve sunmakla birlikte, SFE tabanlı ekstraktlara özgü kalite standartlarının geliştirilmesi ve bu ürünlerin gıda, ilaç ve kozmetik sektörlerinde kullanımına yönelik açık, uyumlu ve sektörler arası koordineli düzenlemeler yatırımcı güvenini artırabilecek kritik bir gelişme olacaktır.

Kırsal kalkınma açısından ise, tarımsal kooperatifler ve üretici birliklerinin atık toplama, kurutma ve taşıma süreçlerine daha etkin şekilde dahil edilmesi önemlidir. Ayrıca, kümelenme ve ortak kullanım modellerinin yaygınlaştırılması, yüksek yatırım maliyetine sahip SFE teknolojilerinde küçük ve orta ölçekli üreticilerin sisteme entegre edilmesini kolaylaştırabilecek bir yaklaşım sunmaktadır.

Sonuç olarak, bu tez Türkiye'de tarımsal atıkların süperkritik akışkan ekstraksiyonu yoluyla biyoaktif bileşiklere dönüştürülmesinin teknik, ekonomik ve sektörel boyutlarını bütüncül bir bakış açısıyla ele almış ve bu atıkların biyoteknolojik dönüşüm potansiyelini ortaya koymuştur. Bulgular, tarımsal atıkların değerlendirilmesi yoluyla sektörel çeşitlenmenin teşvik edilebileceğini, istihdamın artırılabileceğini, ithalat bağımlılığının azaltılabileceğini ve döngüsel biyoekonomi politikalarıyla uyumlu bir kalkınma modelinin inşa edilebileceğini göstermektedir. Bu bağlamda, Türkiye'nin tarımsal üretim altyapısının biyoteknolojik dönüşümle desteklenmesi, yalnızca ekonomik getiriler açısından değil; aynı zamanda sürdürülebilirlik, kırsal kalkınma ve toplumsal refahın güçlendirilmesi açısından da stratejik bir fırsat alanı olarak değerlendirilebilir.

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TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): VALORIZATION OF AGRICULTURAL RESIDUES INTO BIOACTIVE COMPOUNDS: A SUPERCRITICAL EXTRACTION-BASED ECONOMIC PERSPECTIVE FOR TÜRKİYE

TEZİN TÜRÜ / DEGREE: **Yüksek Lisans** / Master ☒ **Doktora** / PhD ☐

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