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PISTACIA TEREBINTHUS L. FRUIT PRODUCTION PROCESS OPTIMISATION: TECHNOLOGICAL AND ENVIRONMENTAL EVALUATION USING SIMULATION TECHNIQUES

M.Sc. THESIS

IN

FOOD ENGINEERING

BY

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ABSTRACT

PISTACIA TEREBINTHUS L. FRUIT PRODUCTION PROCESS OPTIMISATION: TECHNOLOGICAL AND ENVIRONMENTAL EVALUATION USING SIMULATION TECHNIQUES

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The objective of this research is to create a novel process model for the large-scale processing. of *Pistacia terebinthus* L. (menengiç) fruit and assess the model's viability from a technological and financial standpoint. The creation of by-products like menengiç oil, ice cream, cones, and animal feed support materials was included into the study's focus, which was the instant coffee production process.A simulation model with a 10,000 kg/batch raw material capacity was used to build the process design; flow division points were tuned to enhance product diversity. The allocation of product flows affected the production quantities and by-product yields, according to comparisons between scenarios. For instance, 1,017 tons of ash are produced annually even when only 5% of the flow is used for this purpose, but 865 tons of product are produced annually from a 10% ice cream flow.According to economic calculations, raw material expenses made up about 84% of overall manufacturing costs, and the total capital investment (TCI) was estimated to be between 11.01 and 12.98 million USD. Profitability rose with capacity expansion, but it fell sharply with capacity reduction; the internal rate of return (IRR) ranged from 51.51% to 37.72%.The results show that menengiç fruit may be used to make a wide range of high-value food products, not simply coffee, and that capacity planning and product diversification techniques can increase the investment's competitiveness.

Key Words: *Pistacia terebinthus* L., Menengiç ice cream, Techno-economic analysis Simulation

ÖZET

PISTACIA TEREBINTHUS L. (MENENGİÇ) MEYVESİ ÜRETİM SÜRECİ OPTİMİZASYONU: TEKNOLOJİK VE ÇEVRESEL OLARAK SİMÜLASYON TEKNİKLERİ KULLANILARAK DEĞERLENDİRİLMESİ

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Bu araştırmanın amacı, *Pistacia terebinthus* L. (menengiç) meyvesinin büyük ölçekli işlenmesi için yeni bir süreç modeli oluşturmak ve modelin teknolojik ve finansal açıdan uygulanabilirliğini değerlendirmektir. Menengiç yağı, dondurma, külah ve hayvan yemi destek malzemeleri gibi yan ürünlerin oluşturulması, çalışmanın odak noktası olan hazır kahve üretim sürecine dahil edilmiştir.Süreç tasarımını oluşturmak için 10.000 kg/batch hammadde kapasiteli bir simülasyon modeli kullanıldı; ürün çeşitliliğini artırmak için akış bölme noktaları ayarlandı. Senaryolar arasındaki karşılaştırmalara göre, ürün akışlarının tahsisi üretim miktarlarını ve yan ürün verimlerini etkilemiştir. Örneğin, akışın sadece %5'i bu amaçla kullanıldığında bile yılda 1.017 ton kül üretilirken, %10'luk bir dondurma akışından yılda 865 ton ürün üretilmektedir.Ekonomik hesaplamalara göre, hammadde giderleri toplam üretim maliyetlerinin yaklaşık %84'ünü oluşturmuş ve toplam sermaye yatırımının (TCI) 11,01 ila 12,98 milyon USD arasında olacağı tahmin edilmiştir. Kârlılık kapasite artırımı ile artarken, kapasite azaltımı ile keskin bir şekilde düşmüştür; iç getiri oranı (IRR) %51,51 ile %37,72 arasında değişmektedir.Sonuçlar, menengiç meyvesinin sadece kahve değil, çok çeşitli yüksek değerli gıda ürünlerinin yapımında kullanılabileceğini ve kapasite planlama ve ürün çeşitlendirme tekniklerinin yatırımın rekabet gücünü artırabileceğini göstermektedir.

Anahtar Kelimeler: *Pistacia terebinthus* L., Menengiç dondurması, Tekno-ekonomik analiz, Simülasyon

’’Dedicated to my family’’

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LIST OF ABBREVIATIONS

ASM	Animal Supplementary material
AOC	Annual Operating Cost
ChemCAD	Chemical Computer-Aided Design
DC	Direct Cost
DFC	Direct Fixed Capital
FD	Freeze Drying
GP	Gross Profit
HPH	High-Pressure Homogenization
HPP	High-Pressure Processing
HRT	Hydraulic Retention Time
HSYSs	Hybrid Separation Systems
HTST	High-Temperature Short-Time
IC	Indirect Cost
ICC	Ice Cream Cone
IRR	Internal Rate of Return
IT	Income Taxes
MR	Main Revenues
MPC	Main Product Cost
NP	Net Profit
NPV	Net Present Value
OC	Operating Cost
OR	Other Revenues
PBT	Payback Time
PC	Purchased Equipment Cost
Q	Raw Material Processing Size
RMC	Raw Material Cost
SCG	Spend Coffee Ground

SD	Spray Drying
SFD	Spray-Freeze Drying
TCI	Total Capital Investment
TR	Total Revenues
UPC	Unit Production Cost
WC	Working Capital

CHAPTER 1
INTRODUCTION

1.1 Overview of Instant Coffee Production

Coffee's chemical makeup influences its sensory profile and biological activity, making it one of the most popular drinks in the world. The main bioactive ingredients in coffee are caffeine, chlorogenic acids, lipids, proteins, carbs, and a variety of volatile chemicals (Arıoğlu et al., 2021; Vaia, 2023). Although most of the world's coffee comes from top producers like Brazil, Vietnam, Colombia, Indonesia, and Ethiopia, growth factors including temperature, soil type, altitude, and rainfall have a big impact on the quality and flavor of beans (Worku et al., 2018; Wintgens, 2004). The final aroma of brewed coffee is defined by the more than 1,000 volatile aroma molecules that are created as a result of thermal reactions that are started during roasting. (Vezzulli et al., 2023).

Chlogenic acids are recognized for their antioxidant properties and their function in contributing to the bitterness and astringency of the beverage, while caffeine (1,3,7-trimethylxanthine) offers its stimulating effect (Arıoğlu et al., 2021). Furthermore, the Maillard processes that result in the ideal fragrances and mouthfeel after roasting depend heavily on polysaccharides like galactomannans and arabinogalactans, which comprise around 60% of the dry matter of green beans (Vaia, 2023).

Alternative source materials to Coffea arabica and Coffea canephora have been researched in response to the growing demand for plant-based and functional beverages. *Pistacia terebinthus* L. is also referred to as menengiç or terebinth regionally, is one such substitute. Traditionally consumed in Mediterranean countries this fruit mimics coffee’s roasted appearance and aroma, despite being caffeine-free. According to Arıoğlu et al. (2021), roasted menengiç can yield a brew with a coffee-like sensory profile while offering antioxidant benefits. Its rich bioactive makeup cludes phenolic compounds, flavonoids, and unsaturated fats, all of which may support anti-inflammatory and antimicrobial properties. Due to its oil content, menengiç undergoes Maillard transformations during roasting, generating volatile molecules analogous to those in regular coffees (Vaia, 2023). These features make menengiç appealing as a functional ingredient and a regionally-sourced alternative for instant beverage development.

Menengiç, a member of the *Anacardiaceae* family, is a drought-tolerant shrub or small tree widely found in countries bordering the Mediterranean, including Turkey, Italy, Greece, Syria, and Lebanon. It grows well in semi-arid and arid zones, especially on rocky, sunlit terrain ranging from sea level to about 1,500 meters altitude (Kavak et al., 2010).

The fruits of *P. terebinthus* L. are nutritionally dense and rich in health-promoting compounds. On a dry weight basis, they contain approximately 40–60% oil, dominated by unsaturated fatty acids such as oleic acid (50–60%) and linoleic acid (20–30%), which are linked to anti-inflammatory and cardioprotective effects (Gülsoy et al., 2019). The fruits also feature polyphenols like Gallic acid and catechins, flavonoids, and α-tocopherol (vitamin E), which collectively support strong antioxidant activity (Fidan et al., 2023). Furthermore, 8–12% protein, 7–10% dietary fiber, and essential minerals such as potassium, calcium, magnesium, and iron (Seçilmiş et al., 2014) reinforce their nutritional value. These characteristics underscore the plant's suitability as a base material for healthy, caffeine-free coffee substitutes.

There are several processing steps involved in making instant coffee from lipid-rich plant materials like menengiç, which have an impact on yield and quality. Every stage, from washing and roasting to drying and filtering, is essential to the performance of the final product, as proposed by Illy and Viani (2005) and Maroulis and Saravacos (2003). Cleaning and roasting are the first steps in this procedure for menengiç specifically in order to start Maillard reactions and break down fats for the creation of scent (Baggenstoss et al., 2008; Vaia, 2023). Because of the fruit's high lipid content, subsequent grinding increases surface area for effective oil pressing, a crucial step that avoids solubility and encapsulation (Gülsoy et al., 2019). The aqueous extract obtained post-pressing undergoes encapsulation using carriers such as maltodextrin or gum Arabic to stabilize volatiles and improve shelf stability. Drying turns the encapsulated liquid into a soluble powder, commonly via freeze-drying or spray-drying. Filtration is necessary following extraction to eliminate particles and guarantee clarity and dispersibility due to the fibrous nature of Menengiç and the residual seed material (Fidan et al., 2023; Gülsoy et al., 2019). Every unit operation provides chances for equipment, temperature, and time optimization, improving functionality and consistency while lowering environmental impact (Singh et al., 2021).

Flavor, color, and aroma are developed through thermal reactions that are triggered by roasting, including lipid breakdown and Maillard reactions (Baggenstoss et al., 2008; Vaia, 2023). Because of its high fat content, menengiç requires efficient pressing and increased surface area, which is made possible by grinding; too much fat can impair encapsulation efficiency and solubility (Gülsoy et al., 2019). After that, the extracted substance is encapsulated using carriers like Arabic gum or maltodextrin to stabilize volatile chemicals and increase shelf life. Drying methods such as spray drying or freeze drying convert the liquid extract into a stable, soluble powder.
Importantly, due to the fibrous and seed-rich nature of *P. terebinthus*, filtration becomes a mandatory step especially after extraction to remove coarse residues, seed particles, and oil-rich solids that can compromise clarity, solubility, and overall product quality (Fidan et al., 2023; Gülsoy et al., 2019). Each of these stages present unique challenges and optimization opportunities, where improvements in time, temperature, and mechanical efficiency can lead to reduced resource consumption, enhanced product consistency, and minimized environmental impact (Singh et al., 2021).

Recently, the production of different types of ice creams has shown a development worldwide, due to the changing of consumer preference towards functional products. Generally, people prefer more functional, aromatic and different types of ice creams in their diets. Natural additives that are used can give good sensorial properties, nutritional values (such as, vitamins, minerals, organic acids, fiber, antioxidants and color, *etc*.) and health benefits to the ice creams (Granger et al., 2005).

In this context, a portion of the classic instant menengiç coffee produced can be utilized as a functional ingredient in value-added dairy products such as flavored ice cream. Owing to its aromatic profile and antioxidant-rich composition, the powder derived from *P. terebinthus* not only imparts a distinctive flavor but also enhances the functional properties of the final product, offering potential applications in the development of caffeine-free, plant-based dessert alternatives (Fidan et al., 2023; Gülsoy et al., 2019).

In the production of functional ice cream enriched with classic menengiç coffee, the process begins with the preparation of the ice cream premix. At this point, the mixture is supplemented with sugar, skim milk powder, stabilizers, and spray-dried coffee powder. According to Fidan et al. (2023), "when appropriately distributed in the premix, encapsulated menengiç extract enhances the functional and aromatic properties of milk matrices." The purpose of the mixing procedure is to guarantee uniformity and efficient flavor dispersion throughout the mixture. After mixing, the premix is homogenized, which improves emulsion stability, decreases the size of fat globules, and adds to the finished product's creamy texture (Baggenstoss et al., 2008). To remove microbiological impurities and maintain product integrity, the homogenized mixture is further pasteurized. Additionally, pasteurization helps to "preserve heat-sensitive aroma compounds when plant-based additives are added to dairy applications," according to Vaia (2023).To guarantee full hydration of the stabilizers and flavor profile maturation, the pasteurized mixture is cooled and allowed to rest in the refrigerator. "Resting improves both the structural properties and flavor integration of the frozen mixture," according to Gülsoy et al. (2019). A semi-frozen structure starts to form in the following step, which involves passing the mixture through a continuous freezer with air supplied to create overflow. In order to stabilize the product's texture and maintain the volatile compounds included in traditional menengiç coffee, the final hardening step quickly freezes the product. In addition to providing a caffeine-free substitute, this production method uses the menengiç fruit's distinct flavor and antioxidant content (Arıoğlu et al., 2021).

1.2 Importance of Process Optimization

A key problem in food production is process optimization, particularly for activities like the production of ready-to-drink beverages that depend on large energy inputs and intricate multi-step workflows. More control over processing parameters promotes consistent product quality and environmental sustainability in addition to increasing operational efficiency. Systems in the food sector frequently perform below their capacity because of antiquated infrastructure or a lack of automation, as noted by

Maroulis and Saravacos (2003). This can result in excessive energy consumption and changes in the final product's qualities.

Each step in the coffee processing process, including roasting, grinding, and extraction, has a direct impact on sensory attributes like solubility, fragrance, and taste intensity. Illy and Viani (2005) highlighted that by jeopardizing important volatile chemicals, inadequate roasting temperature or time profiles may have an impact on customer approval. Because *Pistacia terebinthus* L. is extremely sensitive to processing variables in terms of fragrance profile and antioxidant value, these difficulties become especially crucial when working with this plant. (Gülsoy et al., 2019).

Menengiç's high lipid content creates special difficulties for powder production and extraction. Unoptimized pressing or filtration can result in issues with flavor stability and solubility, claim Fidan et al. (2023). To achieve a useful final product with a long shelf life, it is crucial to carefully control factors including pressing power, filter particle size, and encapsulating material-extract ratio (usually maltodextrin).
In order to simulate and enhance food processing systems, digital technologies have become indispensable. SuperPro Designer, for instance, offers a platform for assessing various business situations and discovering operational inefficiencies inside units. Misailidis, Pérez Sánchez, and Petrides (2022) proved the value of simulations in the creation of ice cream by showing how they can uncover system dependencies that are frequently missed in conventional design procedures. Their results demonstrate how digital modeling can help with energy usage efficiency and resource allocation. Beyond operational effectiveness, processing optimization makes a significant contribution to environmental objectives. According to Baggenstoss et al. (2008), compared to outdated systems, contemporary, energy-efficient coffee production techniques may cut greenhouse gas emissions by as much as 40%. In addition to improving sustainability outcomes, these technologies encourage the use of biodiversity unique to a place and aid in rural development projects when applied to indigenous raw materials like menengiç.

1.3 Technological Innovations in Coffee Production

Coffee processing has been updated by technological advancements, especially the use of automated processes and real-time monitoring tools. In order to maintain volatile flavor components and avoid over-roasting, roasting systems now allow for accurate temperature and airflow adjustments (Illy and Viani, 2005). *Pistacia terebinthus* L. has a high oil content and an aroma profile that is sensitive to heat, making this level of control especially crucial during processing.

Digital simulation platforms such as SuperPro Designer provide valuable insights into process design and evaluation. According to Misailidis, Pérez Sánchez, and Petrides (2022), these tools help with resource utilization calculations, configuration comparison, and inefficiency identification in complicated food operations. These features are directly applicable to ready-to-drink coffee production, where maintaining quality while minimizing energy input is of critical importance.

New methods including vacuum roasting and microwave-assisted extraction are gaining popularity for menengiç-based ready-to-drink coffee since they can reduce thermal deterioration while maintaining aroma. In contrast to conventional thermal procedures, Baggenstoss and colleagues (2008) demonstrated how well microwave techniques improve flavor preservation. Furthermore, atomization management during spray drying improves the powder's solubility and stability.

Recent developments in encapsulation involve optimizing carriers like maltodextrin and gum Arabic to protect sensitive compounds during drying. Gülsoy et al. (2019) emphasized that precise control of inlet temperature, carrier ratios, and feed rate is essential for achieving a product with favorable sensory and functional traits.

By lowering energy demand, water use, and emissions, technological advancements also help achieve environmental goals. In comparison to conventional systems, innovative techniques can cut energy usage by 20–35% when paired with simulation-based optimization, according to Singh and colleagues (2021). For the sustainable manufacturing of useful beverages like traditional menengiç coffee, this makes novel processing very valuable.

1.4 Environmental Concerns

Because of worries about greenhouse gas emissions, energy use, and water consumption, environmental sustainability has emerged as a key problem in the manufacturing of coffee. Although Coffea Arabica and *Coffea canephora* are the main subjects of research, *Pistacia terebinthus* L. and other alternative raw materials also need to be assessed for their potential environmental effects, particularly when employed in industrial-scale applications like ready-to-drink formulations.

It is commonly recognized that the carbon footprint of coffee manufacturing is greatly increased by the roasting and grinding procedures. According to Giraldi-Díaz et al. (2023), these steps are responsible for almost 60% of the overall emissions from the processing of traditional coffee. Because of its oily nature, Menengiç is challenging to roast and requires more thermal energy. Furthermore, several processes—like oil pressing, particle filtration, and encapsulation—that are less frequently used in conventional coffee workflows demand higher energy and material inputs.

Life Cycle Assessment (LCA) facilitates environmentally conscious decision-making in process design and allows the quantitative quantification of environmental impacts. Early LCA integration aids in identifying important environmental stress points and directs the adoption of cleaner alternatives, according to Gosalvitr et al. (2022). The choice of drying technology, including freeze and spray drying, has a major impact on total energy use and emissions, according to their research. Innovative approaches to heat management, such as heat recovery mechanisms and closed-loop energy systems, are becoming more popular in the context of sustainable coffee production. Kekes et al. (2025) demonstrated that these systems could lower primary energy demand by up to 35%, an outcome particularly relevant to menengiç applications that involve drying and pasteurization.

Another important factor is water utilization. Fidan et al. (2023) pointed out that during menengiç processing, membrane cleaning and repeated rinsing greatly raise freshwater consumption and wastewater production. Process development can assess sustainability-cost trade-offs by modeling water and heat recovery techniques with programs like SuperPro Designer. All of these observations highlight how crucial ecologically friendly design is to the manufacturing of beverages made from menengiç. Utilizing simulation models, integrating heat and water recovery systems, and applying life cycle assessment (LCA) are efficient ways to reduce environmental impacts while promoting the long-term scalability of substitute coffee solutions.

1.5 Research Objective and Scope

This study aims to optimize the production process of instant coffee from the menengiç (*Pistacia terebinthus* L.) plant in order to boost production efficiency and decrease environmental impacts. Alternative goods such gold-type coffee, coffee ice cream, and ice cream cones made from processing leftovers have been simulated in addition to traditional instant coffee. Basic production steps include roasting, oil removal, extraction, encapsulation, and drying are the subject of the study.

The impact of process factors on yield, quality, energy, and water consumption was assessed through the modeling of multiple production scenarios using SuperPro Designer software. Each scenario's effects on the environment were assessed in terms of waste creation and overall input efficiency. Through the use of modeling methodologies and technical advancements, this study seeks to create an integrated and sustainable production model for *P. terebinthus* L.

CHAPTER 2
LITERATURE REVIEW

2.1 Menengic Coffee Production Process

Menengiç, or *Pistacia terebinthus* L., is a Mediterranean shrub or small tree that is widely distributed in southern Turkey, where it is referred to locally as "çedene" or "çitlembik." Özcan (2004) states that the fruit has between 39 and 43 percent oil, which is mostly made up of unsaturated fatty acids like linoleic acid (28%) and oleic acid (53%). The fruit has significant nutritional and industrial potential since, in addition to its high fat content, it contains about 11% protein and is abundant in minerals like calcium and potassium.

The physicochemical characteristics of *P. terebinthus* oils were examined by Gecgel and Arıcı (2009), who found that the fat content ranged from 35 to 47%. According to gas chromatography data, oleic acid (50–53%) is the most prevalent fatty acid, followed by palmitic acid (20–23%) and linoleic acid (19–21%). Because of its low peroxide values (0.45–0.76 meq O_2/kg), the oil has great oxidative stability and can be used in food and cosmetic applications.

Fruits of *P. terebinthus* are a rich source of bioactive substances such gallic acid, catechins, and tocopherols, according to Fidan et al. (2023). Although oleic acid (~50–60%) and linoleic acid (~25–30%) are the main fatty acids, phytochemicals have significant anti-inflammatory, antibacterial, and antioxidant properties. The authors back up the plant's traditional use and promise as a functional food ingredient by highlighting how processing methods and geographic origin affect compositional variations. Roasting is a critical step in developing the flavor and aroma profile of *P. terebinthus* fruits. Durmaz and Gökmen (2011) reported that as roasting temperature increases (100–200 °C), total phenolic content and antioxidant capacity decline, with the greatest losses observed at 200 °C. However, moderate temperatures (100–150 °C) preserve most functional compounds while enhancing sensory attributes. They concluded that precise temperature control is essential to prevent undesirable chemical changes and maintain nutritional value.

Seçilmiş and Göğüş (2014) evaluated different roasting methods—microwave, pan, and combined treatments—and found that roasting prior to oil extraction improved aroma and general acceptability. The most favorable sensory results were achieved using microwave roasting followed by pressing. Seçilmiş (2013) further emphasized that pre-press roasting ensured more uniform heating and higher oil yield, with optimal color and physicochemical properties.

Bölek and Özdemir (2017) optimized roasting conditions using a fluidized bed system and identified 150 °C for 20 minutes as ideal for balancing texture, flavor, and color. Their findings support industrial standardization efforts for consistent menengiç coffee quality. Following roasting, the fruits are ground to increase surface area for subsequent processing steps such as oil extraction and aqueous brewing. The effectiveness of extraction, the strength of the aroma, and the quality of the finished product are all greatly impacted by grinding. According to Justiniano et al. (2022), grind size is crucial since too-large particles weaken the scent, while too-fine particles might cause bitterness and poor solubility. For ready-to-drink menengiç coffee to have the best extraction and the desired sensory qualities, particle size management during grinding is essential.

As *P. terebinthus* fruits have a high lipid content, extracting the oil is a crucial step. According to Kaya and Özer (2020), seeds gathered at Elazığ, Turkey, produced an average oil yield of 47%. They used Fick's second law to compute diffusion coefficients by analyzing variables like temperature, extraction duration, seed-solvent ratio, and particle size (1.15×10^{-11} to 1.86×10^{-11} m^2/s for 0.55 mm particles). According to their findings, oil output was considerably raised by longer extraction times, ideal temperature, and smaller particle sizes. The main fatty acids determined by gas chromatography analysis were palmitic, linoleic, and oleic acids.

Durak and Uçak (2015) optimized solvent composition using a simplex-lattice design, finding that a 39% water–61% acetone mixture produced extracts with high phenolic content (36,392 mg GAE/kg) and strong antioxidant activity. Sür et al. (2024) demonstrated that supercritical CO_2 extraction, especially with ethanol as a co-solvent, improved both oil yield and retention of bioactives like γ-tocopherol at 50 °C and

350 bar, with minimal solvent residue. Ultrasound-assisted extraction has also shown promising results. Özcan et al. (2020) found that 30 minutes of sonication increased oil yield from 38.9% to 42.6% and elevated total phenolics to 467 mg/100 g. Importantly, the fatty acid profile remained stable post-treatment. These studies highlight the importance of process parameter optimization in improving both yield and functional quality of menengiç oil.

In this study, brewing of *P. terebinthus* coffee was conducted at 95 °C for 30 minutes using hot water extraction. There is no peer-reviewed literature that particularly addresses the brewing behavior or extraction kinetics of menengiç tea, despite the fact that this method has been refined based on preliminary experiments and solubility observations. In order to contextualize the process and guide technique development, comparable data from conventional coffee systems have been cited.

The impact of particle size distribution on mass transfer during solid-liquid extraction in conventional coffee was examined by Estévez-Sanchez et al. in 2025. Their results showed that while finer ground coffee offers greater resistance to liquid flow, it also boosts extraction efficiency because of its larger surface area. After creating a mathematical model to predict extraction kinetics, the authors came to the conclusion that efficiency and process stability require the ideal ratio of permeability to extraction rate. Given that menengiç contains components that are rich in oil and might further affect its solubility and flow behavior, this information is especially crucial.

Lashmanova, Ibragimova, and Borisova (2024) used a blend of Arabica and Robusta to compare traditional and modern brewing methods. According to their research, when compared to more conventional techniques like drip brewing or coffee brewing, microwave-assisted extraction yielded the darkest brews and the largest extraction yield (~25%). Additionally, sensory analysis revealed a higher level of bitterness. These findings imply that while sophisticated brewing methods might boost productivity, they must be properly adjusted to avoid sacrificing quality, which is crucial to take into account while creating brewing profiles that complement the distinct makeup of menengiç.

In order to stabilize *P. terebinthus* oil's volatile constituents and enhance shelf life, solubility, and antioxidant retention in ready-to-drink formulations, encapsulation is a crucial step. After optimizing both traditional and microwave-assisted volatile oil extraction from *P. terebinthus cambium*, Karaoğul and associates (2025) carried out encapsulation using spray drying and freeze drying. They discovered that freeze-dried nanocapsulated powders, which had spherical particles of about 33 µm and a crystalline/amorphous ratio of 14.4/85.6, had improved antioxidant activity and structural stability. According to thermal analysis, oil started to leak at 200°C, with a 10% release at this temperature.

Poyrazoğlu et al. (2017) used three wall materials (maltodextrin, inulin, and gum Arabic) at a rate of 14% to assess the impact of spray drying conditions on encapsulation efficiency and color attributes. At 170°C, inulin produced the best color brightness and encapsulation efficiency (~56%). The least effective ingredient was maltodextrin (~16–32%), while the color of Arabic gum varied with temperature. These findings highlight how crucial carrier choice and inlet temperature are to the successful encapsulation of menengiç oil

Yaman et al. (2023) used varying Arabic gum-maltodextrin ratios (75:25 to 25:75) to compare the spray drying (SD), spray freeze drying (SFD), and freeze drying (FD) methods. The ultrasonic nozzle spray drying method produced the highest scent retention rate (73.2%). In addition, SD outperformed SFD and FD with the best encapsulation efficiency (over 90%). Under ideal SD circumstances, volatile molecules like linalool and α-pinene were almost entirely preserved. These findings highlight the critical role of encapsulation method and formulation in maintaining aroma and functionality in menengiç-based instant powders.

Since drying has a direct impact on the solubility, stability, and preservation of the product's functional components, it is an essential step in the preparation of ready-to-drink plant-based beverages. The bioactive and functional qualities of *P. terebinthus* L. (menengiç) extracts can be well preserved by vacuum drying and freeze-drying.

According to Eytemiş (2016), because of its low operating temperature and gentle dehydration method, freeze-drying maintains the highest levels of antioxidant activity (78.12±0.98%) and total phenolic content (40.29±1.23 mg GAE/g dry weight). Vacuum drying demonstrated slightly lower retention values with 35.66±1.08 mg GAE/g phenolic content and 72.94±1.22% antioxidant activity, although being more energy-efficient. In terms of color metrics, the freeze-dried samples were brighter (L*=62.8) than the vacuum-dried powders, suggesting superior visual quality. According to these findings, vacuum drying may provide a balanced approach to quality and energy consumption in the industrial production of menengiç powder, but freeze-drying is recommended to optimize quality.

Bölek (2018) employed freeze-drying to create a soluble powder from fat-free roasted menengiç extract in his work on ready-to-consume *P. terebinthus* L. coffee. The moisture content of the freeze-dried coffee powder was 3.31±0.01%, its total soluble dry matter content was 21.51±0.11 °Brix, and its total fat content was 3.84±0.05%. 5.45±0.02 was the pH value and 58.22±1.76% was the antioxidant activity. With a particle size distribution of D[4,3]=56.32µm, it is a rather small powder that dissolves quickly. Bölek's sensory analysis confirmed that freeze-dried menengiç coffee was well-accepted by consumers in terms of appearance, flavor, and aftertaste. These results confirm that freeze drying effectively preserves the functional and sensory properties of menengiç coffee for high-quality instant product development.

Freeze drying has been applied in the production of instant *P. terebinthus* L. coffee, demonstrating its effectiveness in preserving product quality. However, there is no published study on the use of spray drying for this purpose. In the present work, spray drying was evaluated through process simulation using SuperPro Designer to assess its applicability in industrial-scale menengiç coffee production.

2.2 Ice Cream

Ice cream is a popular frozen dessert widely consumed across the world due to its creamy texture, sweet taste, and refreshing qualities. Traditionally made from a blend of milk, cream, sugar, and stabilizing agents, its formulation has evolved over time to accommodate a growing demand for products with enhanced nutritional value and functional benefits. Beyond its sensory appeal, ice cream's complex structure—comprising air bubbles, ice crystals, fat globules, and a continuous serum phase—makes it a subject of interest in food science. The delicate balance of ingredients and processing conditions plays a critical role in determining its texture, stability, and overall quality. As consumer preferences shift toward healthier alternatives, research into improving ice cream formulations through ingredient innovation and advanced processing techniques has gained momentum. Understanding the physicochemical and functional properties of ice cream is therefore essential for both product development and quality optimization in the dairy and frozen dessert industry.

Genovese et al. (2022) examined functional ice cream enhanced with prebiotics, omega-3s, antioxidants, and fiber. These components supported gut and immune health but often impaired sensory traits like flavor and creaminess. The authors suggest partial substitution of sugar and fat as a better approach to preserve product quality.

Syed et al. (2018) investigated how different stabilizers affect the texture and stability of ice cream, highlighting their roles in preventing phase separation, improving chewiness, and enhancing melt resistance. Table 2.1 summarizes the common stabilizers used and their typical usage ranges. For instance, gelatin (E441) from animal protein is applied at 0.3–0.5% to minimize weeping and foaming. Guar gum (E412), derived from legume seeds, is a strong stabilizer effective at 0.1–0.2%, limiting heat shock and preserving structure. Carrageenan (E407), sourced from red seaweed, is used at 0.01–0.02% in blends to inhibit phase separation. Other gums such as sodium CMC (E466), locust bean gum (E410), and xanthan gum (E415) serve functions like increasing chewiness and stabilizing milkshakes. These findings emphasize that optimal stabilizer type and concentration directly affect product quality, particularly in functional or low-fat ice cream formulations.

Kavaz Yüksel, Şat, and Yüksel (2015) investigated the incorporation of terebinth coffee (*P. terebinthus* L.) into ice cream at concentrations of 0.5%, 1%, and 2%, analyzing its impact on quality attributes. As the concentration increased, notable improvements were observed in total solids, fat content, titratable acidity, viscosity, and both dripping and melting times. Color metrics revealed increased a* and b* values, indicating enhanced redness and yellowness, while L* values, protein content, and pH decreased. Organic acid analysis showed reductions in propionic and orotic acids, and malic acid was not detected. Mineral levels—including Ca, Mg, Fe, K, and Zn—significantly increased with higher additive concentration. Sensory evaluation revealed that the 1% terebinth addition yielded the highest consumer acceptance, balancing enhanced nutritional value with satisfactory flavor and texture. These findings demonstrate that optimized inclusion of terebinth coffee can improve the functional and nutritional profile of ice cream without compromising sensory appeal

Cruz et al. (2022) highlighted that, particularly in high-fat formulations, raising the homogenization pressure dramatically decreases oil droplet size and increases viscosity. The behavior of droplet sizes was described using a log-normal distribution model, and the significance of emulsion management for product stability was underlined. In support of these conclusions, Tosaki et al. (2009) found that, in comparison to conventional techniques, high-pressure homogenization (HPH) up to 97 MPa produced enhanced melt resistance, increased hardness, and decreased shear. Additionally, pressures greater than 5 MPa enhanced the distribution of oil droplets and inhibited the development of ice crystals, strengthening the mixture's structural network. patterns of instability examined under a microscope. Furthermore, Kot and Kamińska Dwórznicka (2024) investigated ultrasonic homogenization at 20 kHz for 5 minutes and discovered that it improved emulsion stability (as evidenced by lower Turbiscan Stability Index (TSI) values of ~1.3–2.2 compared to 2.5–7.3) while marginally reducing viscosity when compared to mechanical methods. Under a microscope, the treated materials showed delayed destabilization patterns and maintained pseudoplastic flow behavior. Together, these investigations demonstrate how the emulsion stability, melting resistance, and textural quality of frozen products can be improved by optimizing both mechanical and ultrasonic-assisted homogenization.

Table 2.1 Common stabilizers used in ice cream and their functional properties Adapted from Syed et al. (2018).

Stabilizer (E Number)	**Source**	**Usage Level (%)**	**Primary Functions**
Gelatin (E441)	Animal protein	0.3–0.5	Prevents wheying-off and foaming
Guar gum (E412)	Guar legume seeds	0.1–0.2	Strong stabilizer, limits heat shock, maintains texture
Sodium CMC (E466)	Modified natural gum	0.1–0.2	Adds body, provides chewiness
Locust bean gum (E410)	Ceratonia siliqua beans	0.1–0.2	Cryo-protective, maintains uniform viscosity
Carrageenan (E407)	Red seaweed	0.01–0.02	Prevents phase separation, used in blends
Xanthan gum (E415)	Microbial fermentation	-	Stabilizes milkshakes and water ices
Sodium alginate (E401)	Brown seaweed	-	Forms gel in presence of calcium and acid
Microcrystalline cellulose (E460)	Cellulose derivative	0.004	Foam stabilizer, helps reduce fat content

Pasteurization and homogenization are essential processing stages that influence both the microbial safety and physicochemical quality of dairy-based ice cream mixes. Dahle and Barnhart (1931) found that high pasteurization temperatures (around 85 °C) effectively reduced microbial load and enhanced emulsifier performance, resulting in finer fat globules (<2 µm) and more stable emulsions with minimal cream separation. In a more recent study, Machado et al. (2023) demonstrated that high-pressure processing (HPP) at 450–600 MPa was more effective than thermal pasteurization (75 °C for 15 s) in eliminating *E. coli* and *L. innocua*, with shelf-life extended up to 51 days. HPP-treated cream also maintained stable pH and color while showing higher viscosity (~0.028 Pa·s) compared to thermally treated cream (~0.016 Pa·s), indicating improved emulsion stability.

Complementing these findings, Bousbia et al. (2021) evaluated the impact of High Temperature Short Time (HTST) pasteurization on milk quality. As shown in Table 2.2, total aerobic bacteria decreased from 1.2×10^6 to 7.2×10^6 CFU/mL following HTST treatment. Additionally, slight reductions were observed in protein (from 3.2% to 3.0%) and lactose (from 4.7% to 4.5%) content, while viscosity declined moderately. Importantly, sensory attributes improved, with enhanced taste and odor compared to untreated milk. These studies collectively underscore the role of both thermal and non-thermal pasteurization methods in optimizing the safety, texture, and sensory appeal of dairy-based ice cream formulations.

Table 2.2 Effects of HTST Pasteurization on Key Milk Parameters (Bousbia et al., 2021)

Parameters	**Before HTST**	**After HTST**
Total aerobic bacteria (CFU/mL)	1.2×10^6	7.2×10^4
Protein (%)	3.2	3.0
Lactose (%)	4.7	4.5
Viscosity	Moderate	Slightly lower
Taste and odor	Mild	Enhanced

Figure 2.1 illustrates the reduction in microbial load (CFU/mL) before and after HTST pasteurization. A steep decline in total viable count is evident in both raw and

reconstituted milk, reinforcing the efficiency of the thermal process. Figure 2.2 displays sensory evaluation results, where treated samples scored slightly lower in viscosity and color but showed a marginal increase in odor and flavor perception. These findings highlight a trade-off between microbial safety and some sensory attributes. The study concludes that HTST pasteurization, while highly effective in enhancing shelf life and safety, may induce subtle but measurable changes in milk's sensory and nutritional profiles. Therefore, optimizing time-temperature conditions is critical to maintaining quality while ensuring public health.

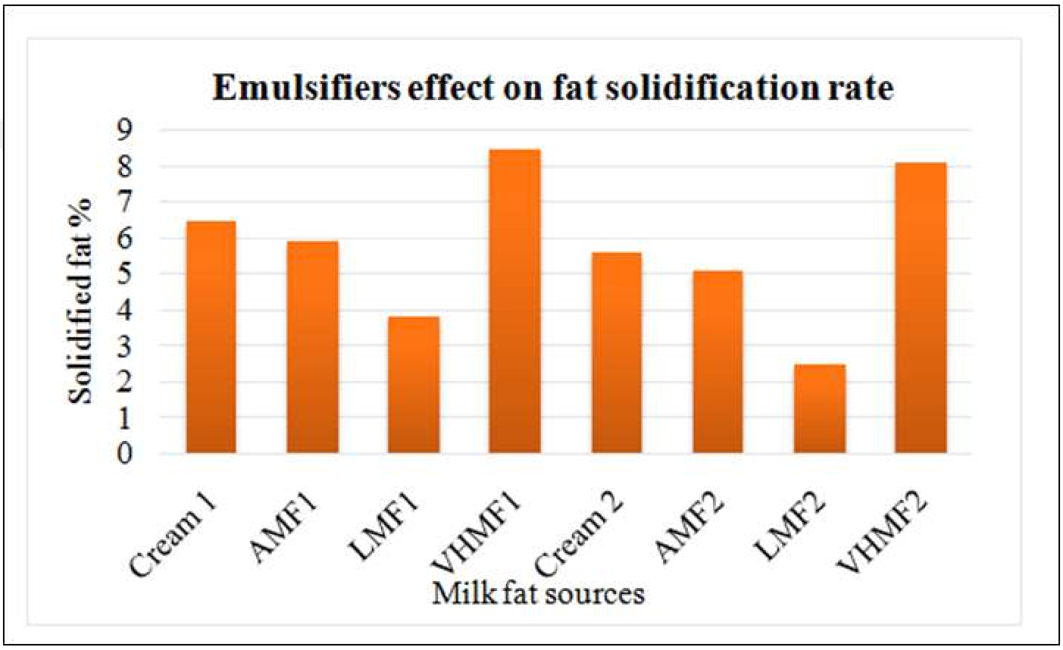

Figure 2.1 Visual data from HTST milk quality analysis (Bousbia et al., 2021)

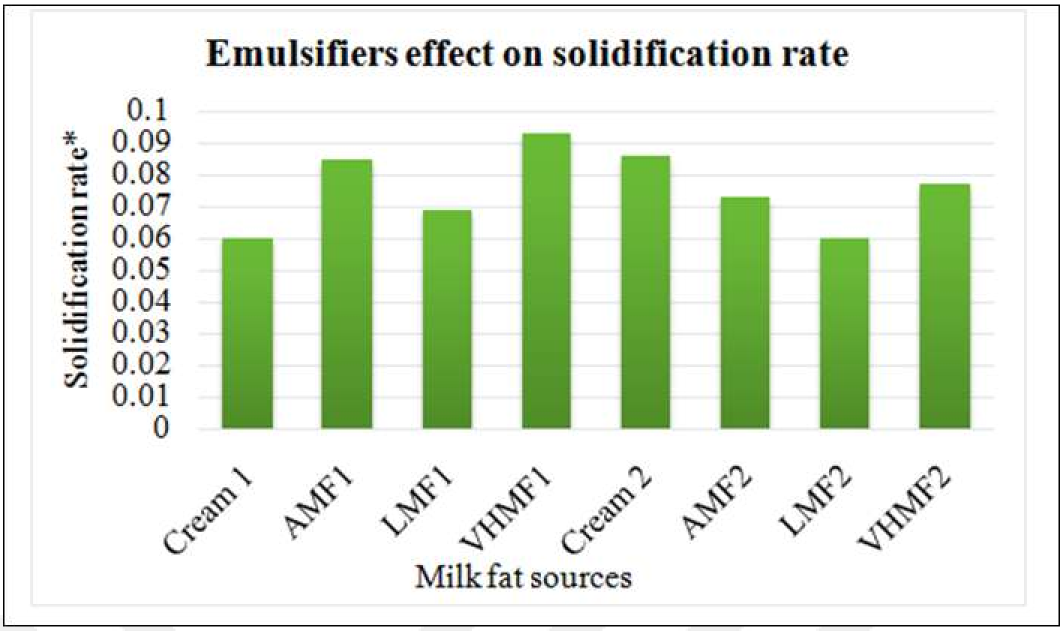

Figure 2.2 Visual data from HTST milk quality analysis (Bousbia et al., 2021)

Aging is a critical step in ice cream manufacturing that influences the physicochemical and sensory characteristics of the final product. Studies have demonstrated that aging the mix at low temperatures (typically 0–4 °C) leads to improved viscosity, emulsification, and air incorporation capacity. Doğan and Kayacier (2007) assessed the rheological evolution of Kahramanmaraş-style ice cream mix aged at 0 °C for up to 60 h. The mix's apparent viscosity (η_2) and consistency index (K) steadily increased during aging, peaking around 24 h, while the flow behavior index (n) decreased, indicating enhanced shear-thinning behavior. These changes suggest the development of a more cohesive structure ideal for aeration during freezing.

In another study, Akalın et al. (2008) investigated the effects of different aging times (4 h vs. 24 h) and storage temperatures (–10 °C and –20 °C) on ice cream made with 10% milk fat. Results showed that prolonged aging led to higher viscosity, overrun, and firmness, while melt resistance improved primarily with storage at –20 °C. Sensory evaluation favored samples aged 24 h, especially in terms of body and texture. Tvorogova et al. (2020) examined how aging influences ice crystal morphology in ice creams with 3% and 6% fat. Microscopic images in Figure 2.3 reveal that aged samples contain finer, more homogeneously distributed ice crystals after hardening, contributing to a smoother mouth feel. Meanwhile, Figure 2.4 shows a slight shift in crystal size after 3 months of storage, from ~32–36 µm to ~37 µm, reflecting minor recrystallization. These findings confirm that aging improves initial structural integrity but highlight the importance of controlling storage conditions to maintain long-term quality.

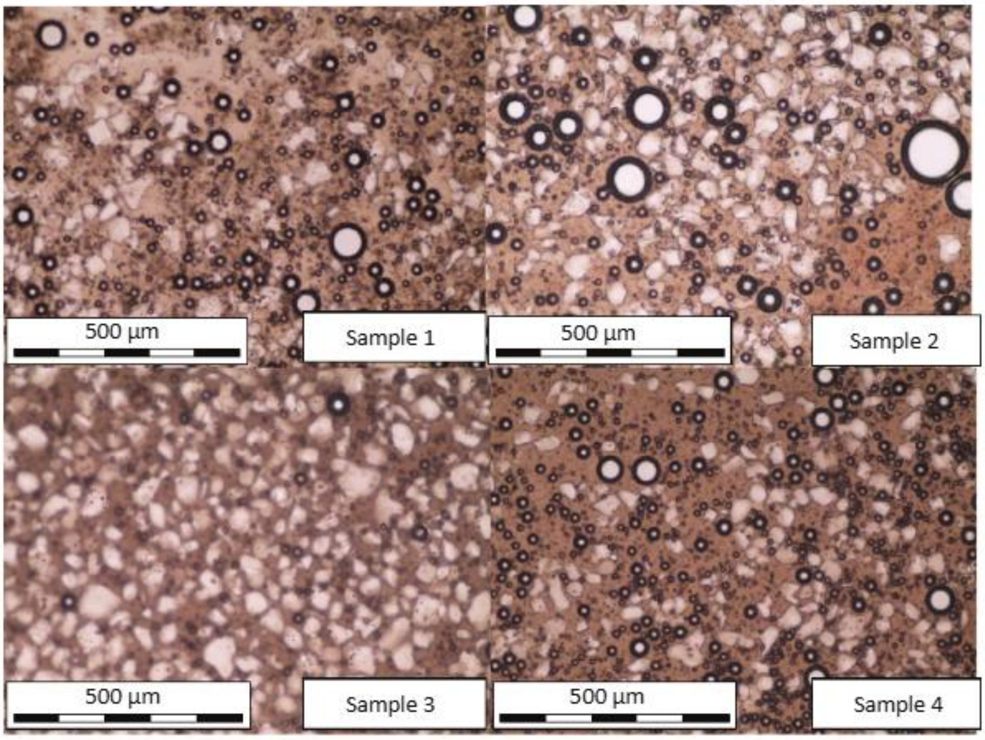

Figure 2.3 Microphotographs of ice crystals in experimental ice cream samples after hardening (Tvorogova et al., 2020).

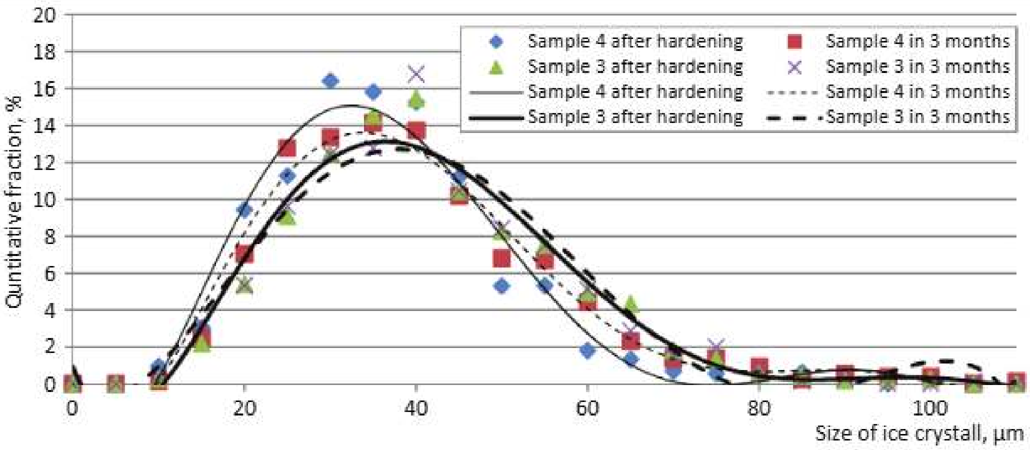

Figure 2.4 Size distribution of ice crystals in ice cream with a fat mass fraction of 6%: after hardening and after 3 months of storage (Tvorogova et al., 2020).

Voronin et al. (2021) explored the effects of high-pressure-jet (HPJ) processing (0–500 MPa) on the rheology and microstructure of 6% fat ice cream. Pressures ≥400 MPa

led to reduced density, larger particles, and more non-Newtonian behavior before freezing. After hardening, HPJ-treated samples showed greater firmness (~3,800 g) but melted faster. Microscopy revealed disrupted casein micelles and aggregated proteins, indicating a denser matrix, though optimization is needed to reduce meltdown rate.
Patel et al. (2013) modeled a batch hardening system to minimize freezing time and energy usage. Factors like air velocity, temperature, box geometry, and airflow direction were evaluated. They found that –40 °C air with optimal box spacing reduced freezing time but increased energy consumption. A 90-minute cycle offered a good compromise between freezing speed and energy efficiency.

Muse and Hartel (2004) developed predictive models showing that melt resistance and hardness depend on fat destabilization, ice crystal size, overrun, and viscosity. Smaller crystals and well-structured fat networks improved both firmness and meltdown resistance, underlining the importance of controlling microstructure during processing.
Sitnikova and Tvorogova (2019) examined how storage temperature affects ice cream texture. Storage at –18 °C caused ice crystals and air bubbles to grow significantly over six months, while samples held at –25 °C retained finer structures. They recommend maintaining –25 °C to preserve product quality during long-term storage.
Kozłowicz et al. (2019) tested zinc and *Lactobacillus casei* enrichment in ice cream. Zinc reduced pH and viscosity and slightly increased lipid oxidation, but overrun and melt behavior were stable. Probiotic viability remained above 10^6 cfu/g, with highest survival in zinc–probiotic samples. Sensory scores were unaffected, supporting the feasibility of functional ice cream development.

2.3 Ice Cream Cone

Fatmawati, Nur'aini, and Karyantina (2023) explored novel ice cream cone formulations that blend wheat flour with tofu dregs flour and varying concentrations of beetroot extract (30–50%) using a factorial CRD design. They assessed three flour ratios (90:10, 80:20, 70:30) combined with three levels of beetroot extract for their A study exploring wheat-tofu flour and beetroot extract ratios found that a 70:30 blend with 30% beetroot provided the highest protein content (13.55%), while a 90:10 mix with 50% beetroot showed peak betacyanin levels (0.074 mg/100 g). Sensory tests favored the 80:20 ratio with 30% beetroot, scoring highest in color, taste, aroma, and crispness (~4.07/5). Tofu flour improved texture, but beetroot extract above 30%

reduced consumer acceptance due to intense color and earthy notes. The study suggests that combining tofu dregs with moderate beetroot levels enhances both nutrition and sensory quality in cones.

Mahulkar et al. (2024) used a simplex-lattice mixture design to develop multigrain ice cream cones from ragi, buckwheat, amaranth, and bajra flours. Among 20 tested blends, the optimal formula (20% ragi, 20% buckwheat, 40% amaranth, 20% bajra) showed highest scores in crispness (7.81), color (7.29), and acceptability (7.86), with a holding time of ~2,118 s and desirability index of 0.85. Table 2.3 summarizes storage results over 50 days: while microbial and moisture levels rose, phenolics and antioxidant activity declined significantly. The product maintained safety and texture early in storage, but bioactive compound losses were notable over time.

Mahulkar et al. (2024) investigated the development and optimization of waffle-type ice cream cones using millet flours, including finger millet, buckwheat, amaranth, and pearl millet. Through a simplex lattice mixture design, twenty formulations were evaluated for structural, functional, and sensory properties. The optimized formulation—comprising 20% ragi, 20% buckwheat, 40% amaranth, and 20% pearl millet—exhibited superior sensory scores: crispiness (7.81), color (7.29), and overall acceptability (7.86), along with an extended ice cream holding time of approximately 2,118 seconds.

Shelf life analysis was conducted over 50 days, during which several quality parameters deteriorated. Moisture content increased from 4.55% to 9.08%, microbial load rose from 0.62×10^4 to 1.57×10^5 CFU/g, and peroxide value climbed from 0.42 to 1.46 meq/kg. Simultaneously, there was a notable decline in functional bioactive components: total phenolic content dropped from 695.58 µg GAE/g to 182.32 µg GAE/g, flavonoid content decreased from 2.42 mg quercetin/g to 1.30 mg/g, and DPPH antioxidant activity was reduced drastically from 93.25% to 5.08%. These findings emphasize the initial functional and sensory potential of multigrain cones, while also highlighting the need for improved preservation strategies to maintain quality during storage.

Mohammed et al. (2023) evaluated the effects of adding spent coffee grounds (SCG) to ice cream cone formulations on nutritional value, sensory quality, and starch digestibility. Five variants (ICC-0 to ICC-20) were prepared with SCG levels from 0% to 20%. SCG addition increased fiber and phenolic content, enhancing nutritional properties. However, sensory quality declined at SCG levels above 10%.

As shown in Table 2.3, cones with 5% and 10% SCG had similar sensory scores to the control, while higher levels (15–20%) caused noticeable drops in taste, crispness, and overall acceptability. Notably, general acceptance dropped from 1.27 (ICC-0) to 0.90 (ICC-20), highlighting consumer resistance to excessive SCG. These findings emphasize the importance of balancing nutritional benefits with sensory limitations when incorporating by-products like SCG.

Table 2.3 Sensory Evaluation of Ice Cream Cone Formulations with Spent Coffee Grounds

Attribute	ICC-0	ICC-5	ICC-10	ICC-15	ICC-20
Color	8.13 ± 1.20[a]	8.08 ± 0.76[a]	8.12 ± 0.97[a]	8.02 ± 1.09[a]	7.84 ± 0.77[a]
Smell	7.84 ± 0.77[a]	8.15 ± 0.76[a]	8.05 ± 1.31[a]	7.91 ± 0.72[a]	7.76 ± 0.98[a]
Taste	8.09 ± 1.26[a]	8.11 ± 0.76[a]	8.17 ± 0.92[a]	8.04 ± 1.07[a]	7.68 ± 1.02[a]
Crispness	8.05 ± 1.29[a]	8.13 ± 0.92[a]	8.23 ± 0.85[a]	8.00 ± 0.75[a]	7.55 ± 0.97[a]
General Acceptability	8.15 ± 1.27[a]	8.09 ± 0.75[a]	8.12 ± 1.22[a]	8.01 ± 1.10[a]	7.78 ± 0.90[a]

The symbol ICC-X denotes the ice cream cone formulation, where 'X' represents the percentage of spent coffee grounds.

These findings were visually confirmed through Figure 2.5 (a–g), which illustrated the physical appearance of the ice cream cones. As SCG content increased, the cones exhibited a darker hue, more uneven surface, and a speckled texture, especially apparent in images (d), (f), and (g). This visual change corresponds to the integration of coffee particles and increased fiber, confirming successful ingredient incorporation but also highlighting potential consumer perception challenges. The study concluded that SCG can serve as a functional ingredient in bakery-type frozen products, yet its inclusion must be optimized to balance nutritional benefits with sensory quality and visual appeal.

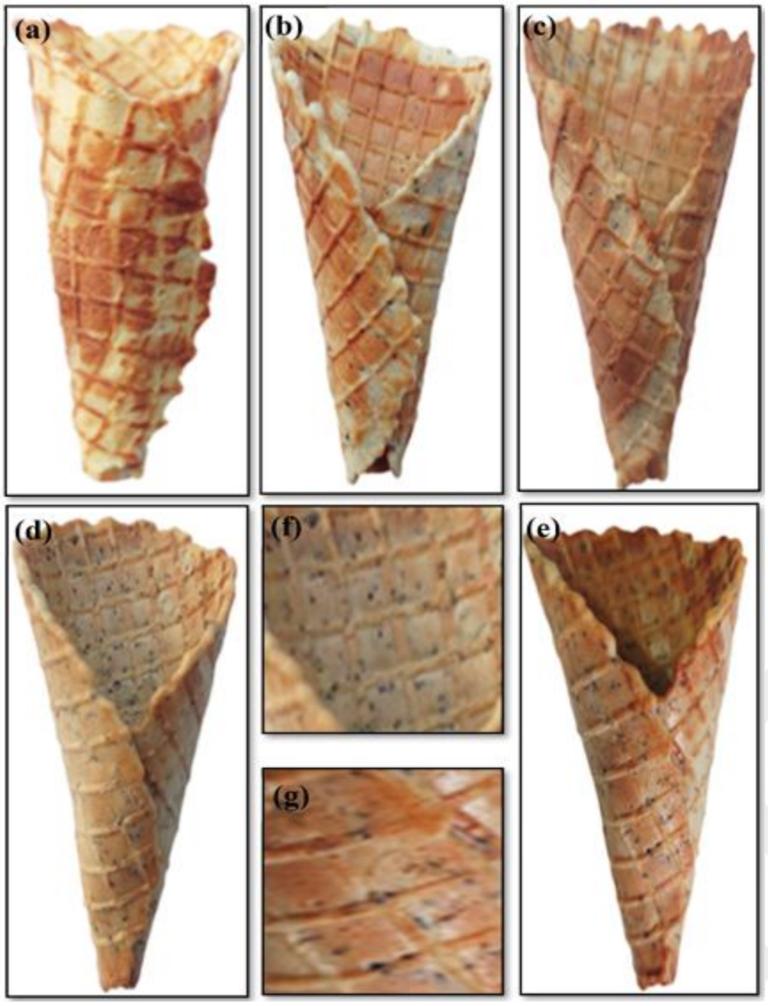

Figure 2.5 Samples of ice cream cones fortified with spent coffee grounds. (a) ICC-0. (b) ICC-5. (c) ICC-10. (d) ICC-15. (e) ICC-20. (f) Surface of ICC-15. (g) Surface of ICC-20. The symbol ICC-X denotes the ice cream cone formulation, where the letter "x" denotes the percentage of spent coffee grounds. (Adapted by author based on Mohammed et al. 2023)

2.4 Optimization in Food Processing

In recent years, optimization efforts in food processing have increasingly focused on enhancing energy efficiency, minimizing waste, and improving product quality, particularly in the context of plant-based raw materials. Among these, *Pistacia terebinthus* L. (menengiç) has garnered attention due to its high oil content and bioactive compounds.

In multi-step processes such as drying, extraction, and encapsulation, the optimization of variables like temperature, duration, and solvent ratio plays a decisive role in determining the final product quality. Bousbia et al. (2009) highlighted the advantages

of low-temperature drying to preserve aromatic compounds, which is especially relevant for raw materials such as menengiç that contain volatile bioactives.
Process simulation tools have emerged as valuable instruments in this context. Several studies in the literature demonstrate the use of platforms like SuperPro Designer to simulate mass and energy balances, allowing comparative evaluations of various production scenarios (Singh et al., 2021). These tools enable researchers to assess not only the main product but also the incorporation of secondary outputs—such as menengiç extract-enriched ice cream—and the valorization of process residues like coffee brewing cake.

Some recent studies have explored the integration of plant-based by-products into cold dessert formulations, such as ice cream, which opens new opportunities for both sustainable production and the development of functional foods (Muzykiewicz-Szymańska et al., 2022). Moreover, the reuse of post-extraction solid residues as animal feed contributes to lowering the environmental footprint of the production chain an additional dimension of process optimization.

In light of this literature, the production of menengiç-based products requires a comprehensive evaluation and optimization of every step, from extraction parameters to final product formulation, to achieve both high-quality outcomes and cost-effective, environmentally friendly manufacturing.

2.5 Environmental Impact of Coffee Production

The environmental footprint of coffee production is shaped by several key stages, ranging from cultivation and harvesting to roasting, drying, and packaging. Among these, drying methods—particularly freeze-drying and spray-drying—play a critical role in determining the overall energy consumption of the process. While spray-drying gives a higher throughput at the expense of some quality trade-offs, freeze-drying is generally more energy-intensive, even though it is good at retaining aroma and bioactive chemicals (Kwakye et al., 2021).In addition, water usage during washing and roasting, as well as emissions associated with packaging and transport, contribute significantly to the environmental burden of coffee processing.

Using fundamental sustainability standards, the environmental impact of each process—from making menengiç beer to making ice cream and cones—can be evaluated. These include the amount of energy needed for drying operations (such spray or freeze drying), the amount of water used for roasting or mixing, and the emissions from formulation and encapsulation.

2.6 Process Simulation

Process simulation is one tool used to create and optimize production steps. There is a virtual representation of the industrial process. The physical, chemical, and/or biological properties of every process step in the production phases must be thoroughly understood in order to employ simulation tools effectively. Process simulation software explains the processes involving products and their flows in the manufacturing stages, computes mass and energy balances for pertinent activities, and does economic evaluations. Finding the ideal production conditions for the process being studied is the primary objective of this type of software. The early 1960s saw the introduction of process simulators, primarily in the petrochemical sector. HYSYS, SuperPro Designer, Aspen Plus, and ChemCAD are a few of the most widely used process simulation tools.

Process simulations are necessary for the design and optimization of production models. There are various advantages to simulation. In practical production, choosing the appropriate technology and standards can be costly and time-consuming. Realizing these procedures as quickly and cheaply as feasible has a direct impact on the production system's profitability. Following model development, a series of simulations can be used to evaluate the impact of production factors and technologies on system profitability, as seen in Figurfe 2.6.

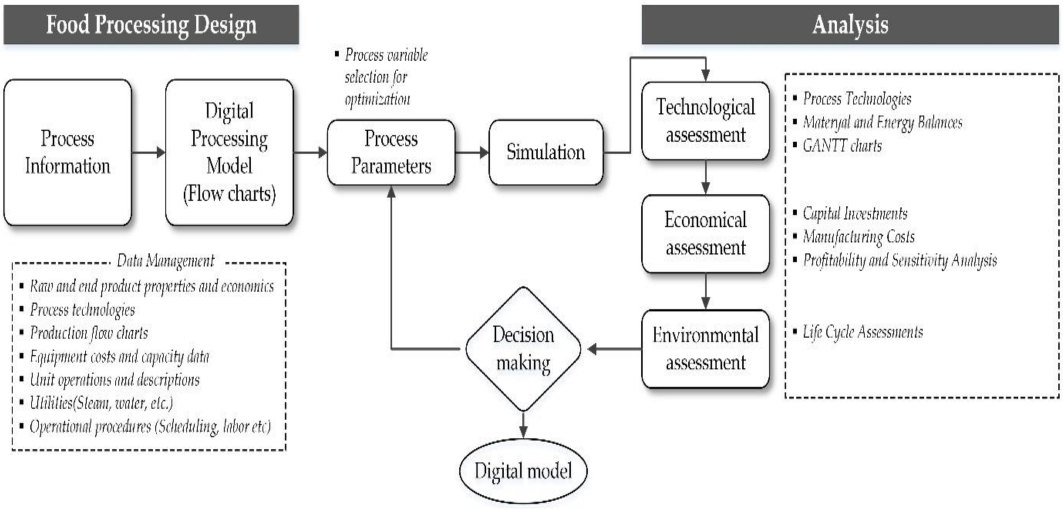

Figure 2.6 Process simulation flow chart

Simulation tools have become indispensable in designing and optimizing food production systems, enabling virtual testing of process configurations prior to industrial implementation. Software platforms such as SuperPro Designer, Aspen Plus, MATLAB, and Simulink are widely used to model mass and energy flows, evaluate process efficiencies, and estimate operational requirements (Singh et al., 2021). These tools allow researchers to compare alternative processing routes and assess the impact of parameter changes on product yield, energy consumption, and environmental load. According to Maroulis and Saravacos (2003), process simulation supports effective decision-making in food engineering by identifying critical stages that affect performance and cost. Similarly, García-Martínez et al. (2022) demonstrated how simulation-based modeling can be applied to dairy-based dessert production to evaluate thermal processing, mixing, freezing, and packaging steps in terms of material usage and energy demand. These approaches are particularly useful when developing integrated product lines, as in this study, where menengiç extract is processed into instant coffee, flavored ice cream, and ice cream cones under different simulated scenarios.The ability to predict energy requirements, equipment sizing, and waste generation helps optimize process design and supports sustainable production strategies.

2.7 Economic Analysis

Using a variety of methods and tools, food and process engineers can create goods, technology, and manufacturing facilities. As computer technologies have advanced, the margin for error in design processes has significantly decreased. The impact of changes in capacity or other physical characteristics on the design and the outcomes of further optimization studies may now be rapidly evaluated. Simulation studies make it easier to evaluate data quickly. Any modifications to data values made with conventional methods frequently necessitate repeating laborious procedures. But these changes may be estimated and made in a matter of seconds because of computer technologies. More accurate economic assessments are made possible by optimizing simulation findings, which aids prospective investors in making wise choices. Calculations employing mass balance are used to determine the equipment capacity needed for each process stage. Cost estimates for the necessary equipment can be finished once the necessary capabilities have been established. The first steps in creating a manufacturing process are evaluating the technology needed to generate a desired product or figuring out the raw materials that are available. Four essential components must be integrated in order to evaluate such a procedure economically:

i. Technical evaluation of the production process, including mass balances, equipment specifications, and capacities;
ii. Plant location based on key elements like raw material availability and market accessibility;
iii. Operational requirements for production management, such as control systems, laboratory infrastructure, inventory/production management systems, and human organization;
iv. Economic analysis that takes into account operating costs, capital investments, and profitability considerations.

A factory design must have a profitable potential in comparison to other investment alternatives in order to qualify as a legitimate investment. Any investment's main goal is to maximize return at the lowest feasible cost. Risk evaluations must also be done, particularly when contrasting the investment with alternative possibilities. Production and investment are the two primary pillars of economic analysis. Figure 2.7 displays the cash flow of a production and investment process. Working capital and fixed capital are typically the two primary components of investment costs. Fixed capital investment is the sum of money required from the time land is purchased until production, including trial runs, begins.

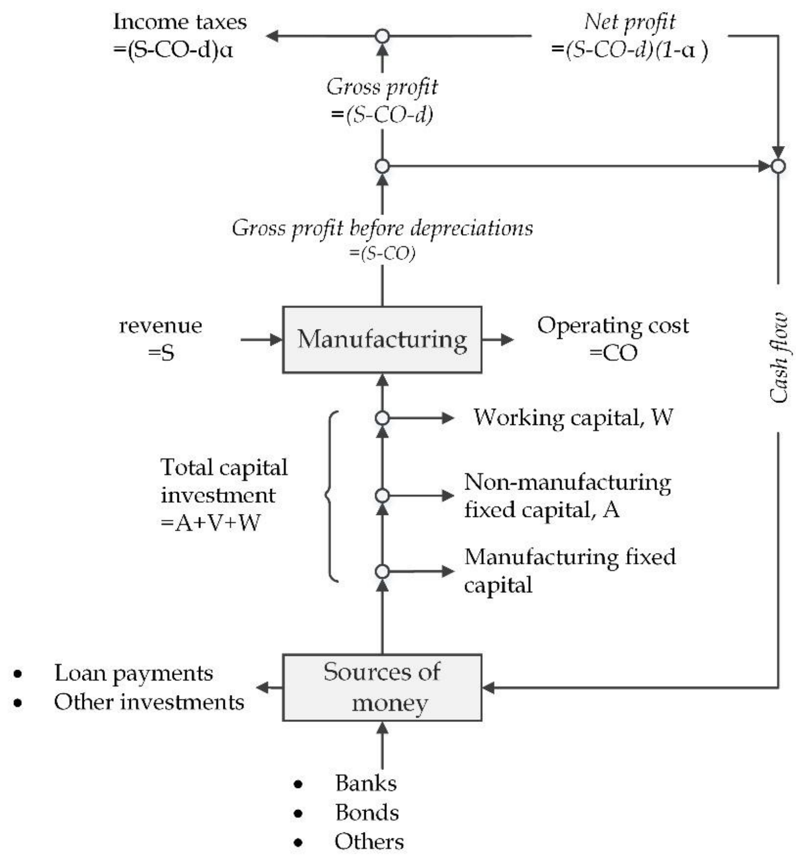

Figure 2.7 Cash flow for investment

Figure 2.8 depicts the behavior of cash flow over time. In this graph, the horizontal axis represents time, while the vertical axis represents money. The time period prior to zero corresponds to the investment phase, whereas the period following zero represents the production phase. The negative (–) region of the vertical axis indicates a deficit in initial capital, while the positive (+) region reflects the point at which the project begins to generate profit. This graph is used to determine the cumulative cash position, demonstrating the point at which the capital initially invested in the project is fully recovered through generated revenues. Any income obtained beyond this point is considered profit. The total profit at the end of the project's life cycle includes the net profit, working capital, and the residual value of the plant and land.

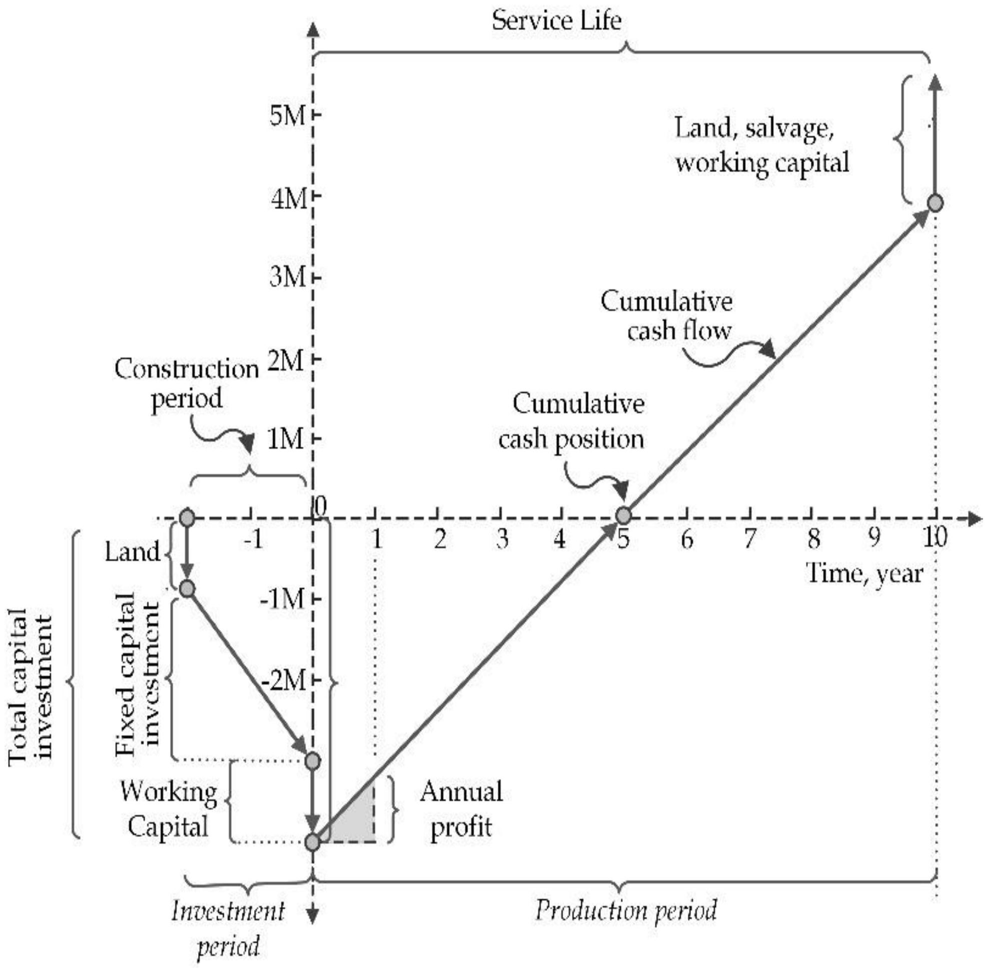

Figure 2.8 Cumulative cash position (Peters & Timmerhaus, 1991)

2.8 Previous Case Studies

Previous studies in the field of food manufacturing have demonstrated the effective application of simulation tools, optimization algorithms, and life cycle assessment (LCA) techniques to evaluate and improve processing systems. Although no direct simulation-based modeling has been reported for *Pistacia terebinthus* L. (menengiç) in the literature, various studies involving coffee and ice cream processing offer relevant insights.

Pazmiño et al. (2022) performed a life cycle assessment (LCA) to evaluate the environmental impact of instant coffee production under different energy scenarios, including coal, natural gas, and renewables. The study covered the full process—from roasting to spray drying—and identified spray drying as the most energy-intensive and emission-heavy stage. Results showed that renewable energy significantly reduced both carbon emissions and total energy use. The authors emphasized that cleaner energy integration can substantially lower the carbon footprint of instant coffee manufacturing, offering valuable insights for sustainability-focused process optimization.

In order to optimize the roasting process of Robusta coffee beans and raise their sensory characteristics to Arabica standards, Ratanasanya and colleagues (2022) created a thorough model-based framework. The work started with the development of a predictive kinetic model that connected important quality markers like color, acidity, and aroma components to roasting parameters like time and temperature. To find the best roasting settings, this model was then combined with an optimization method. Experimental validation of the improved profiles showed that certain heating techniques could greatly enhance the Robusta beans' sensory profile. More significantly, this study demonstrated how process modeling may be used to practically improve the quality of low-quality coffee varietals by roasting interventions guided by science, in addition to being useful for prediction.

In order to analyze how energy recovery and optimization techniques could enhance the environmental sustainability of the coffee processing business, Kekes and colleagues (2025) carried out a thorough life cycle assessment (LCA). Based on an actual industrial plant, the study looked at both baseline and upgraded scenarios, including heat recovery, process integration, and upgrades to energy-efficient equipment. According to the findings, putting such energy optimization techniques into practice significantly decreased the carbon footprint and the overall impact on the environment. Reusing thermal energy and better process planning, in particular, were important factors in lowering the energy usage per kilogram of processed coffee This study shows how life cycle assessment (LCA) can be used as a guide for designing sustainable processes in food production, including coffee production, in addition to being a diagnostic tool.

A comparative life cycle assessment (LCA) was carried out by Konstantas and associates (2019) to investigate the environmental effects of well-known chocolate and vanilla ice cream items that are sold in the UK. The study looked at every phase, from the source of raw materials to the end of life, and found that dairy products—especially milk and cream—are the main cause of environmental problems like eutrophication and the possibility for global warming. The consumption of power for cold storage and production was also found to be a major hotspot. It's interesting to note that chocolate types have more environmental effects than vanilla, mostly because of where the cocoa products came from. The study also evaluated the impacts of various packaging designs and distribution strategies, demonstrating that home storage and consumer mobility have significant environmental repercussions. The authors emphasized the need for targeted interventions in ingredient selection, energy efficiency, and supply chain logistics to improve the overall sustainability of ice cream products.

Misailidis et al. (2022) employed SuperPro Designer to carry out a techno-economic simulation of an industrial-scale vanilla ice cream facility. The system was designed to operate in two 12-hour shifts, achieving an estimated annual output of 7,200 metric tons. Approximately 60% of this quantity was intended for 1 kg tubs, while the rest was processed into chocolate-coated stick formats. The study provided detailed assessments of capital costs (around USD 20 million), operational expenditures, equipment sizing, and energy and material balances. The internal rate of return (IRR) was calculated between 24–25%, with a payback period of under five years. Sensitivity analysis revealed that net present value (NPV) was particularly sensitive to raw milk pricing and financing conditions; profitability declined when milk exceeded USD 1.50/L or interest rates rose above 24%.

In addition to quantitative analysis, the authors presented a detailed process flow diagram generated within the SuperPro Designer environment, showcasing the interconnected stages of vanilla base mix preparation, chocolate coating, and packaging. This diagram was visually represented to provide a clearer understanding of the modeled production sequence. A modified version of this process flow is included in this thesis as Figure 2.9, serving as a visual reference for how simulation platforms can be used to structure and evaluate real-world food manufacturing systems.

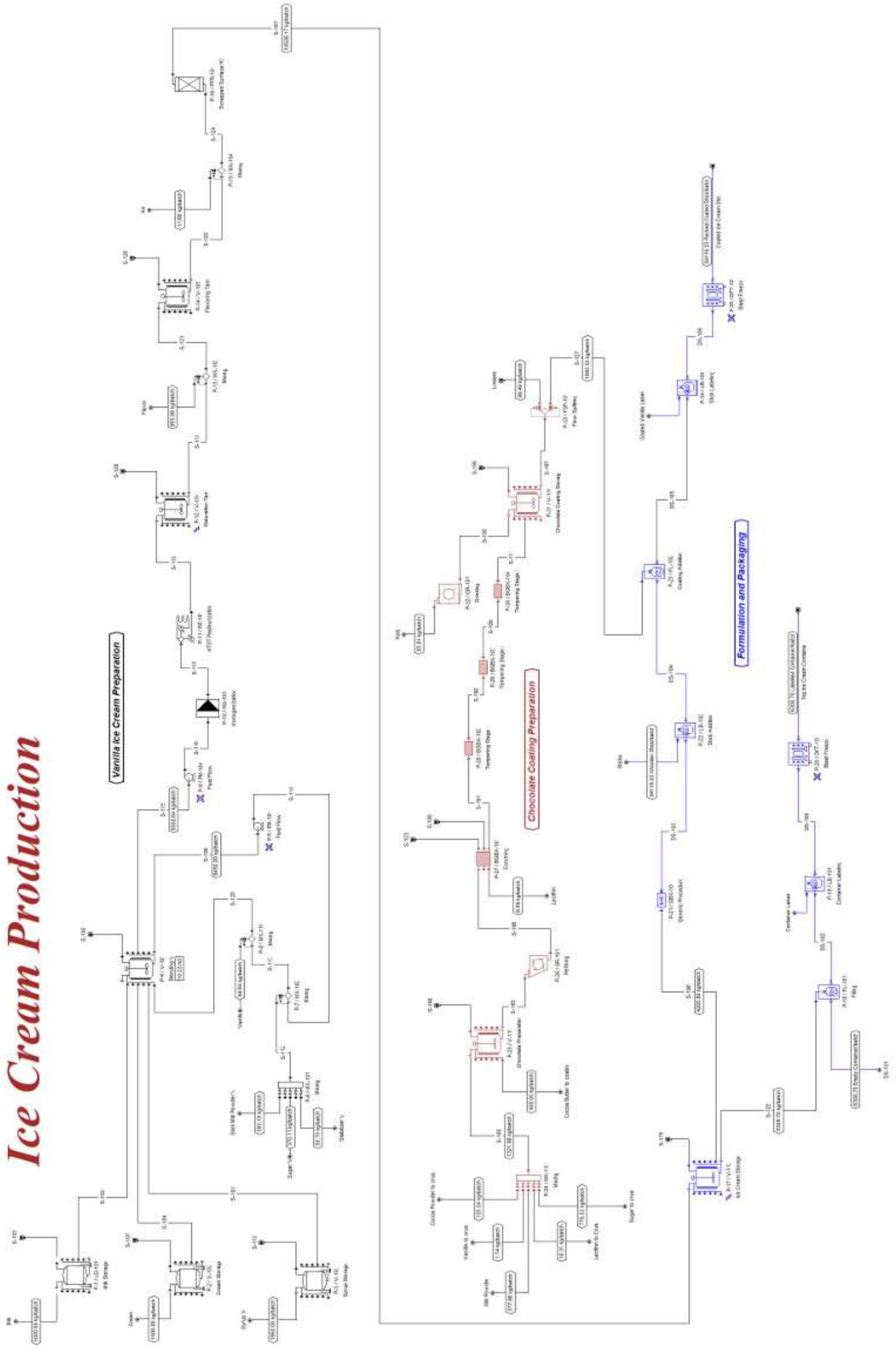

Figure 2.9 Process flow representation developed in SuperPro Designer for industrial-scale vanilla ice cream manufacturing. The model illustrates the integration of vanilla mix preparation, chocolate coating, and final packaging stages. (Misailidis et al., 2022)

CHAPTER 3
MATERIALS AND METHODS

3.1 Process Simulation Studies

The viability of producing menengiç coffee types, ice cream, and cone was evaluated taking into account both technical and financial considerations. The manufacturing system was designed, modeled, and process simulations were carried out using SuperPro Designer 12.0 (Intelligen, Inc., Scotch Plains, NJ, USA). Figure 3.1 displays the simulated process's workflow diagram. For information on input parameters and processing conditions, the literature was examined. Based on the designed process flows, six simulation scenarios were constructed to assess the techno-economic performance of producing instant coffee and value-added by-products from menengic. Scenario 1 involves only the core processes required for instant coffee production, including menengic brewing followed by encapsulation and drying. Scenario 2 follows a similar structure but additionally incorporates the ice-cream cone manufacturing process, allowing for partial utilization of by-products and enhancing material valorization. Scenario 3 further expands the system by introducing the ice-cream premix processing step, enabling a more diversified product output while still including the main coffee production stages. Scenario 4.1 represents a fully integrated process chain that includes instant coffee, ice-cream premix, full ice-cream processing, and cone manufacturing under a constant raw material input of 10,000 kg per batch. Scenario 4.2 mirrors this full integration but applies a reduced input size of 7,500 kg/batch to evaluate the impact of scale on operational efficiency. Finally, Scenario 4.3 simulates a small but completely diverse production setup by combining all of the previously listed processes with an additional decreased input of 5,000 kg/batch. To evaluate the impact of process factors on product yield and profitability, a number of simulation scenarios were created.

This study used a systematic methodology to evaluate the technical and economic aspects of an integrated processing system for the production of three different products: cones, ice cream, and Menengiç instant coffee. Figure 3.1 shows the comprehensive process simulation and optimization flowchart for the integrated menengiç processing system's technical and financial evaluation. First, information was gathered about the menengiç composition and process flow, which are the fundamental inputs of the processing system. Other criteria were defined using these data, and a number of simulation scenarios were created. The performance of the process under different parameters was analyzed in each scenario throughout the appropriate process simulation phase. The simulation produced a number of technical and financial performance parameters, including Efficiency, Unit Production Cost (UPC), Payback Period (PBT), and Internal Rate of Return (IRR). An optimization research based on these response elements was carried out in order to statistically model the impact of process parameters and identify optimal process conditions. Under ideal circumstances, independent technical and economic assessments were carried out for every production line. By considering variables including production capacity, energy consumption, cost-effectiveness, and return on investment, these analyses sought to evaluate each process's performance separately.

In the following phase, an integrated structure for the use of energy and resources was created by combining three distinct process lines into a single integrated operation. After this integration, a technical and financial analysis of the integrated operation was carried out, and the system's overall performance was reassessed. A profitable and sustainable menengiç-based production model was created by optimizing and evaluating both the integrated production structure and individual operations using this thorough technique.

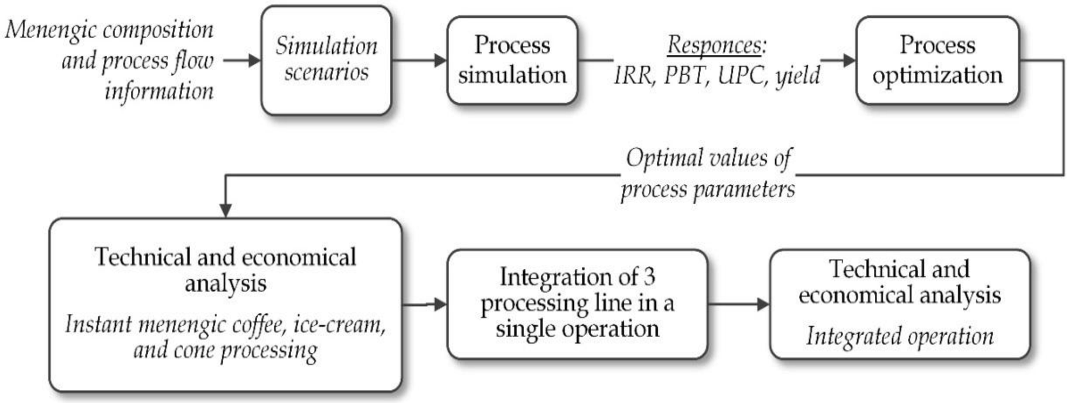

Figure 3.1 Workflow diagram of current process simulation study

3.1.1 Process Model Description

In this study, an integrated process model was developed for the production of instant, classic, and gold menengiç coffee from raw *Pistacia terebinthus L.* fruits using SuperPro Designer simulation software. The developed model not only includes core operations such as roasting, extraction, and drying but also evaluates the potential for by-product recovery and alternative product development, such as cone manufacturing and ice cream production. The process flow and all unit operations were created based on real operational parameters, equipment capacity, and energy consumption assumptions. The simulation model was designed to assess material flow, energy intensity, and cost under different product scenarios.

A total of six scenarios (1, 2, 3, 4.1, 4.2, and 4.3) were developed to evaluate the process under various production combinations. While scenarios 1 to 3 focus solely on menengiç coffee production through encapsulation and drying, scenarios 4.1 to 4.3 include by-product utilization by integrating cone and ice cream manufacturing stages. Figure 3.2, shows the simulation-based production layout and product paths. Table 3.1, provides a matrix of included processing blocks for each scenario. The raw material input (Q) was fixed at 10,000 kg/batch for scenarios 1–4.1 and reduced to 7,500 and 5,000 kg/batch in scenarios 4.2 and 4.3, respectively, due to resource partitioning for cone and ice cream outputs.

Each unit operation in the process was defined with detailed operational parameters such as temperature, retention time, throughput, and final product moisture content. Equipment selection was based on standard industrial units, and associated costs were estimated using SuperPro Designer's internal equipment database and capacity scaling models.

A comprehensive summary of all 30+ unit operations (P2–P25, P26–P36) is presented in Figure 3.2**,** including: The production process begins with solid storage (P2), where menengic fruits are conditioned by storing them at 25 °C for 12 hours, ensuring raw material availability and operational continuity. The vibrating screen (P3) then removes foreign materials and coarse particles from the raw fruits at a throughput of 2,500 kg/h, which enhances the efficiency of subsequent processing steps. After initial cleaning, the fruits undergo roasting (P5) at 200 °C for 20 minutes to develop the desired aroma and flavor profile. Immediately after roasting, a component splitting unit (P3 again) partially removes volatile compounds and fatty acids to standardize aroma characteristics, particularly relevant for quality control.

Following thermal treatment, the product is subjected to cooling (P34) to 50 °C using a heat exchanger system before entering the grinding phase (P7), which reduces the particle size to enable efficient extraction. After grinding, screw pressing (P8) is applied to separate menengic oil, which is reused in cone production, aligning with waste valorization principles. The de-oiled material proceeds to the leaching process (P9), where approximately 90% of the proteins and water-soluble compounds are extracted to form the primary ingredient for instant products. To adjust product concentration and moisture content, especially in GOLD formulations, a design specification step (P35) is employed.

Next, the extract enters drum drying (P26), reducing the moisture content to 1% within 30 minutes, although at a high energy cost. Residual material is then processed through flow splitting (P36), where 95% is diverted for animal feed and 5% is utilized in cone production. For cone manufacturing, ingredients are re-ground in secondary grinding (P27) and mixed with sugar, flour, and fibers in cone constituent mixing (P28), followed by custom mixing (P29) at a 9:1 ratio of base to additives. The resulting mix is stabilized in a reactor-holding tank (P30) and subsequently dried in the cone dryer (P31) until 3% final moisture content is achieved. The cones are then cooled to 25 °C using a cooling system (P32) to preserve structure and extend shelf life.

Parallel to this, encapsulation for instant coffee begins with maltodextrin solution preparation (P11) and custom mixing (P12) of the extract at a 0.1 ratio. This mixture is divided through flow splitting (P13) into GOLD (20%) and CLASSIC (80%) streams. GOLD products undergo freeze drying (P14) to achieve 5% moisture via sublimation, while CLASSIC variants are processed through spray drying (P15) over 90 minutes. Additionally, a portion of the extract is routed via flow splitting (P10) into ICE cream production.

For the ice cream line, Group 1 mixing (P17) incorporates milk, sugar, and stabilizers, which is then reinforced via custom mixing (P16) with a 1:1 additive blend. Separately, Group 2 mixing (P18) prepares aroma and thickening agents, after which all components are merged in final mixing (P19) at a 4:1 ratio. The homogenized blend (P20) is processed at 18°C for 75 minutes to optimize texture, followed by pasteurization (P21) at 72 °C for microbial safety. A small portion of air is incorporated (P22) to increase volume, and the mixture is aged (P23) for 8 hours at 8–9 °C. Final structure is achieved through freezing (P24) at -5 °C and stabilized in hardening (P25) at -18 °C.

The simulation allowed for real-time comparison of each scenario in terms of raw material conversion, product output, process efficiency, and utility consumption. Scenario-specific data such as energy consumption per unit mass, total equipment cost, and by-product utilization efficiency will be analyzed in the subsequent sections of this thesis.

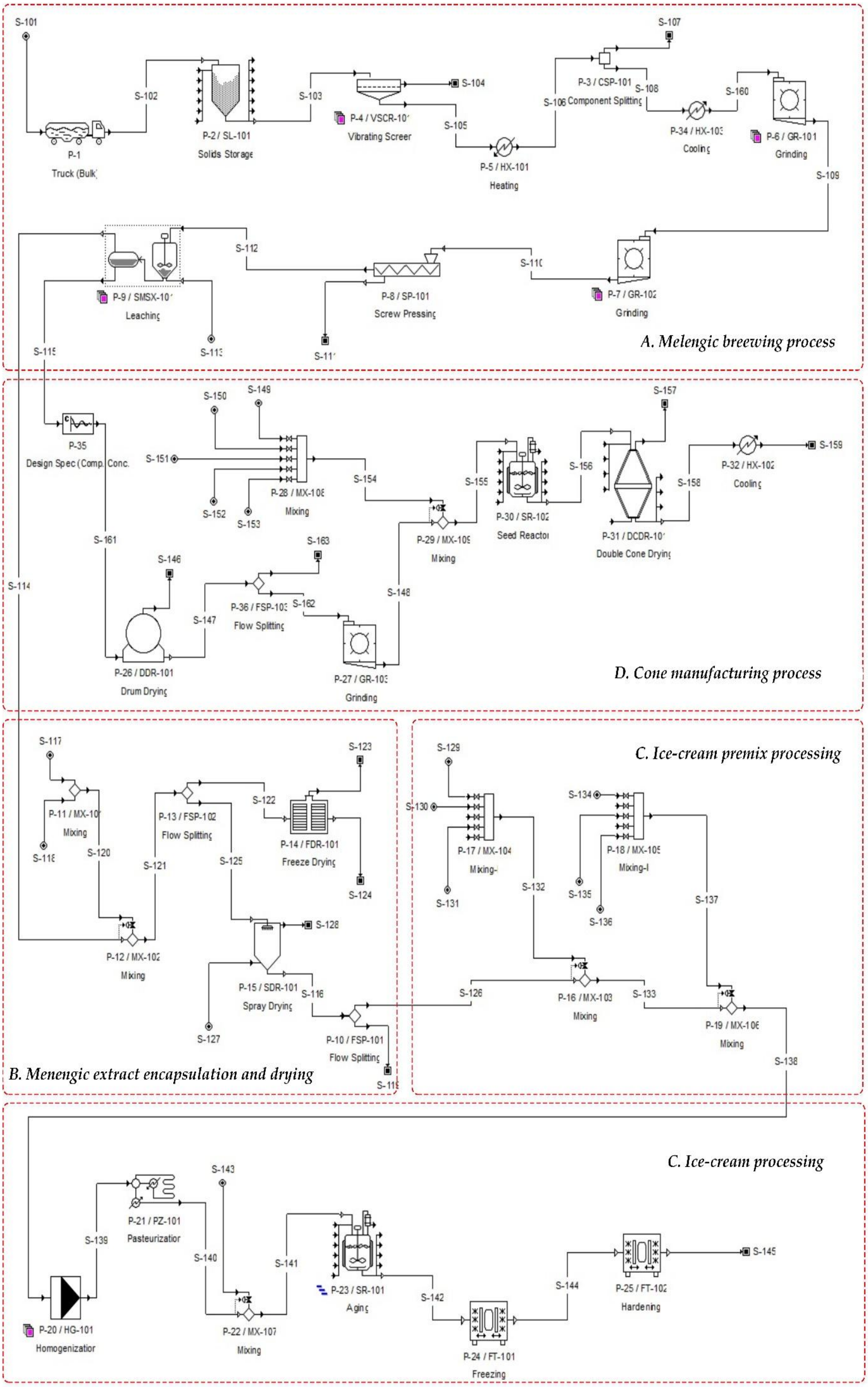

Figure 3.2 Integrated simulation models of menengiç processing

Table 3.1 Instant coffee production from menengiç and by-product process scenarios

Sections	Simulation Scenarios					
	1	2	3	4.1	4.2	4.3
A. Menengic brewing process	✓	✓	✓	✓	✓	✓
B. Menengic extract encapsulation and drying	✓	✓	✓	✓	✓	✓
C. Ice-cream premix processing	-	-	✓	✓	✓	✓
C. Ice-cream processing	-	-	✓	✓	✓	✓
D. Ice-cream Cone manufacturing process	-	✓	-	✓	✓	✓
Raw material processing size, Q (kg RM/batch)	10,000	10,000	10,000	10,000	7,500	5,000

Table 3.2 Process descriptions and equipment specifications for all scenarios. (Q: 10,000 kg/batch)

ID	Process	Operational parameters	Equipment properties and cost
P2	Solid storage	Storage temperature=25 °C, time=12 h	Volume = 20 MT, $ 25,000
P3	Vibrating Screen	For. Mat. Separation, time=1 h	Max. Throughput rate = 2,500 kg/h, $8,000
P5	Heating (Roasting)	Roasting temp= 200 °C, time= 20 min.	Max. heat tr. Area=4 m^2, $50,000
P3	Component splitting	Volatile fatty acid separation = 1 %	Max. Throughput rate = 30,000 kg/h
P34	Cooling	Cooling temp= 50 °C	Max. heat tr. Area=20 m^2, $57,000
P7	Grinding	Time=1 h	Max. Throughput rate = 2,500 kg/h, $40,000
P8	Screw Pressing	Time=1 h (Oil separation)	Max. Throughput rate = 10,000 kg/h, $15,000
P9	Leaching	Main solutes=Proteins, 90% extracted	Max. Throughput rate = 5,000 L/h, $200,000
P35	Design Spec.	Manipulated stream = S-113 (10 % water by mass)	
P26	Drum Drying	Final MC=1%, time =30 min	Drying capacity=592 kg/h, $25,000
P36	Flow Splitting	S-163 (Animal supplement mat.) (%)=95, S-162 (Cone) (%)=5	Max. Throughput rate = 3,000 kg/h
P27	Grinding	Time=1 h	Max. Throughput rate = 2,500 kg/h, $40,000
P28	Mixing	Cone constituent mixing	Max. Throughput rate = 1,350 kg/h
P29	Custom Mixing	Mix-in amount/Process amount=9	Max. Throughput rate = 1500 kg/h
P30	Reactor-Holding	Holding time=30 min	Volume=2,000 L, $25,000
P31	Cone drying	Final MC=3%, time = 1 h	Volume=5,000 L, $80,000
P32	Cooling	Cooling temp= 25 °C	Max. heat tr. Area=1 m^2, $9,000
P11	Mixing	Maltodextrin solution preparation	
P12	Custom Mixing	Mix-in amount/Process amount=0.1	Max. Throughput rate = 4,500 kg/h
P13	Flow Splitting	S-122 (GOLD) (%)=20, S-125 (Classic) (%)=80	Max. Throughput rate =4,500 kg/h
P14	Freeze Drying	Final MC=5%	Max. Sublimation capacity=600 kg, $400,000
P15	Spray Drying	Final MC=5%, time =90 min	Drying capacity=1500 kg/h, $540,000
P10	Flow Splitting	S-126 (ICE) (%)=10, S-125 (Classic) (%)=90	Max. Throughput rate =5,800 kg/h
P17	Mixing	Ice-cream first group constituent mixing	Max. Throughput rate = 300 kg/h
P16	Custom Mixing	Mix-in amount/Process amount=1	Max. Throughput rate = 1,200 kg/h
P18	Mixing	Ice-cream second group constituent mixing	Max. Throughput rate = 2,350 kg/h
P19	Custom Mixing	Mix-in amount/Process amount=4	Max. Throughput rate = 5,800 kg/h
P20	Homogenization	Temp=18 °C, time=75 min.	Max. Throughput rate = 600 L/h, $2,850

P21	Pasteurization	Past. Temp = 72 °C, time 15 min.	Max. Throughput rate = 5,500 L/h, $25,000
P22	Custom Mixing	Mix-in amount/Process amount=0.1 (Air incorporation)	Max. Throughput rate = 6,400 kg/h
P23	Aging	Holding time=8 h, T=8-9 °C	Volume=5,000 L, $25,000 (4)
P24	Freezing	T=-5 °C	Volume=5,000 L, $30,000
P25	Hardening	T=-18 °C	Volume=5,000 L, $30,000

3.1.2 Economic Model Description

With an estimated accuracy of ±20% for operating cost and total capital investment estimations, this model is based on a preliminary economic analysis methodology that is widely acknowledged in the literature (Peters & Timmerhaus, 1991; Green & Perry, 2008).

The total capital investment includes both fixed capital costs, which comprise physical equipment and plant infrastructure, and working capital, which covers expenses like staff salary, raw material stockpiles, product storage, and other operating cash requirements. The estimation of direct fixed capital (DFC) was based on the total equipment purchase cost (PC) (Table 3.3). The equipment costs for the majority of the process units were calculated in this study using the integrated cost calculation capabilities in SuperPro Designer. Additionally, the costs of particular pieces of equipment, including centrifuges, dryers, and storage tanks, were ascertained by obtaining bids from a local manufacturer.

Important components of running costs, such as labor, raw materials, power, and water, were estimated using current prices from local market data. In a similar vein, prices in local commercial markets were used to calculate the selling prices of the products. Projected production volumes and local market demand were matched to estimate the base case production capacity.

The process's economic viability was evaluated using a variety of profitability parameters, including internal rate of return (IRR), payback duration, unit production cost, and unit investment cost (Dursun et al., 2020b).

Table 3.3 Preliminary economic analysis methodology coefficients for investment cost estimation

Total equipment purchases cost (PC)	**Sum of listed equipment costs**	
Direct cost (DC)	Piping (A)	=0.25*PC
	Instrumentation (B)	=0.10*PC
	Insulation (C)	=0.03*PC
	Electrical facilities (D)	=0.10*PC
	Buildings (E)	=0.20*PC
	Yard improvement (F)	=0.10*PC
	Auxiliary facilities (G)	=0.10*PC
	DC	=PC+A+B+C+D+E+F+G
Indirect cost (IC)	Engineering (H)	=0.10*DC
	Construction (I)	=0.10*DC
Others (OC)	Contractor's Fee	=0.05*(IC+DC)
	Contingency	=0.10*(IC+DC)
Direct Fixed Capital (DFC)		=DC+IC+OC
Working Capital (WC)	30 days' of labor, raw materials, utilities, and waste treatment expenses	
Total Capital investment (TCI)		=DFC+WC

CHAPTER 4
RESULTS AND DISCUSSION

A comprehensive technological and economic evaluation of a project typically encompasses the determination of both investment and working capital requirements, alongside profitability assessments. These profitability analyses are subject to various influencing parameters. To examine the sensitivity of economic outcomes to such variables, sensitivity analysis is frequently employed, particularly within the context of industrial applications.

Pistacia terebinthus L., traditionally consumed in local markets and regional culinary practices in a manner similar to conventional coffee, currently lacks a standardized industrial-scale processing framework aligned with modern production standards. The present study seeks to identify alternative utilization strategies for this underutilized fruit and subsequently assess the economic feasibility of these proposed applications. In the initial phase of the study, a process simulation was developed based on a flow model adapted from instant coffee production systems. This model also incorporates the recovery of terebinths oil—a high-value compound naturally present in the fruit. In the subsequent phases, the system was expanded to include the production of terebinths-flavored ice cream and ice cream cones. The economic and operational implications of incorporating these additional product lines were evaluated using advanced simulation methodologies.

4.1 Technological Aspects of Processing

The equipment capacities and specifications required for the production of instant coffee and other high value-added products derived from *Pistacia terebinthus* L. fruit are presented in Table 3.2. Similarly, the integrated production flow and its respective process stages are illustrated in the simulation model flow diagram in Figure 3.2. The primary production line within this model is dedicated to instant coffee production, while potential processing routes for by-products have also been integrated into the system. A detailed process summary for instant coffee production from *Pistacia terebinthus* is provided in Table 4.1. This table includes both the mass quantities and the compositional characteristics of the raw materials and final products. In the simulation study, the base processing capacity was defined as 10,000 kg of *Pistacia terebinthus* L. fruit per batch. The simulation model incorporates multiple decision points regarding the distribution of final products. One such decision point occurs following the brewing-leaching stage (P-9), where the residual grounds are processed through a splitting operation (P-36). At this stage, 5% of the flow is directed towards cone production (S-162), while the remaining 95% is allocated to the production line for animal feed support material (S-163). Accordingly, as shown in Table 4.1, under the base processing capacity, 1,017 kg of cones and 2,811 kg of animal feed support material are produced.

Similarly, in the splitting operation designated as P-13, 20% of the process stream is directed towards gold-type instant coffee production (S-122), while the remaining 80% is allocated to the classic instant coffee production line (S-125). However, since instant coffee is intended to be used as an ingredient in ice cream production, the quantities presented in Table 4.1 may vary depending on the volume of ice cream produced. The amount of ice cream produced, in turn, is influenced by the splitting operation at stage P-10. In the proposed scenario, according to the P-10 splitting process, 10% of the stream (S-126) is directed towards ice cream production, while the remaining 90% (S-124) results in classic-type instant coffee. Based on the base processing capacity, this configuration yields 1,300 kg of classic-type instant coffee, 362 kg of gold-type instant coffee, and 1,447 kg of ice cream.

The rationale behind the relatively low allocation rates for ice cream and cone production lies in the high yields obtained at the final product level. Despite only 5% of the stream being directed toward cone production, 1,017 kg of cones are obtained per batch. This is due to the utilization of 10% of the solid fraction derived from the drying of the slurry remaining after the leaching stage, processed in the custom mixing unit (P-29). A similar situation applies to ice cream production: in the P-10 flow splitting operation, 10% of the stream is allocated to ice cream, while the remaining portion is used for classic instant coffee production. The allocation ratio observed in the P-13 flow splitting operation is primarily based on market analysis, which indicates a higher consumer preference for classic-type instant coffee.

Simulations were conducted based on the scenarios defined in Table 3.1, and the resulting annual mass outputs are presented in Table 4.2. In Scenario 1, only gold-type and classic-type instant coffee were produced, with comparable quantities observed across nearly all scenarios. Scenario 2 builds upon the first by incorporating additional production lines for cone products and animal feed support material. Scenario 3 further extends Scenario 1 by integrating an ice cream production line. The final scenario includes all processing streams proposed in the model. Table 4.3 presents the analysis of production capacity variations within the comprehensive model encompassing all process stages.

Table 4.1 The stream summary of raw material and final product contents in all scenarios (Q: 10,000 kg/batch)

Streams	S-101	S-111	S-119	S-124	S-145	S-159	S-163
Total Contents	10000.0000 (100.00%)	5415.9474 (100.00%)	1302.6218 (100.00%)	361.8394 (100.00%)	1447.3576 (100.00%)	1017.2993 (100.00%)	2811.5645 (100.00%)
Ash	100.0000 (1.00%)	1.0000 (0.02%)	-	-	-	9.1609 (0.90%)	94.0500 (3.35%)
Carbohydrates	-	-	-	-	-	455.9848 (44.82%)	-
Cellulose	2700.0000 (27.00%)	27.0000 (0.50%)	-	-	-	133.6500 (13.14%)	2539.3500 (90.32%)
Corn Syrup	-	-	-	-	277.8926 (19.20%)	-	-
Fats	5100.0000 (51.00%)	4855.5384 (89.65%)	125.3631 (9.62%)	34.8231 (9.62%)	222.3487 (15.36%)	6.9829 (0.69%)	18.3788 (0.65%)
Fibers	-	-	-	-	-	13.2344 (1.30%)	-
for. Mat.	200.0000 (2.00%)	0.1000 (0.00%)	-	-	-	0.4950 (0.05%)	9.4050 (0.33%)
maltodextrin	-	-	278.1516 (21.35%)	77.2643 (21.35%)	30.9057 (2.14%)	-	-
Milk P	-	-	-	-	86.8415 (6.00%)	-	-
Proteins	1300.0000 (13.00%)	13.0000 (0.24%)	833.9760 (64.02%)	231.6600 (64.02%)	127.2812 (8.79%)	86.3426 (8.49%)	122.2650 (4.35%)
Sucrose	-	-	-	-	85.2747 (5.89%)	266.3587 (26.18%)	-
Vanillin	-	-	-	-	-	13.3179 (1.31%)	-
Water	600.0000 (6.00%)	519.3089 (9.59%)	65.1311 (5.00%)	18.0920 (5.00%)	609.5763 (42.12%)	31.7720 (3.12%)	28.1156 (1.00%)
Xanthan gum	-	-	-	-	7.2368 (0.50%)	-	-

4.2 Economic Aspects of Processing

Accurate estimation of the Total Capital Investment (TCI) critically depends on the precise determination of total equipment costs. Table 4,2 summarizes the results of the economic evaluation derived from an industrial-scale process simulation. The simulation was conducted to model the production of high-value-added products from *Pistacia terebinthus* L. (Figure 4.2).

In this study, each proposed scenario was assessed independently. The total capital requirement, covering all equipment necessary for the processing of all streams in which *Pistacia terebinthus* L. is utilized, was estimated at approximately USD 13 million. The proposed process is designed to handle 10 metric tons of terebinth fruit per batch. Equipment costs represent roughly 25% of the total capital investment, while the remaining components were estimated using standard cost-estimation correlations and computer-based scaling factors, as described by Peters and Timmerhaus (1991).

The working capital requirement was estimated based on the operational expenditures required to sustain 30 days of continuous production, including costs related to labor, raw materials, utilities, and waste management. A critical factor in the scale-up of industrial processes is the unit investment cost, which serves as a key determinant of the overall economic feasibility of the system (Cong, 2013).

While the total capital investment required for the production of instant coffee from *Pistacia terebinthus* L. alone is estimated at approximately USD 11 million, it increases to around USD 13 million in the simulation model that incorporates all processing streams.

Across all scenarios, processing *Pistacia terebinthus* with an annual raw material input of 72,000 metric tons and a batch frequency of approximately 600 per year yields a total annual production cost of about USD 30 million. Notably, raw material expenses represent approximately 84% of the total production costs. This proportion aligns with the general trend in agricultural production systems, where raw material costs typically constitute the largest share of total production expenditures. Previous studies examining the impact of raw material costs on process profitability have consistently shown a strong negative correlation, particularly in scenarios involving high-cost raw materials (Misailidis et al., 2009; Wood et al., 2014).

The final economic assessment for all scenarios at baseline capacity encompasses capital investment, operating expenses, and key financial performance indicators, a summary of which is provided in Table 4.2. In this evaluation, the individual effects of four distinct production streams are examined, with profitability analysis results indicating that the internal rate of return (IRR) declines as the degree of integration increases, whereas the payback period (PBT) correspondingly lengthens (Figure 4.1). Table 4.3 presents an additional analysis, summarizing the simulation results on the relationship between installed capacity and profitability. The findings reveal that profitability improves markedly with increasing capacity, as evidenced by a substantial rise in IRR and a corresponding reduction in PBT (Figure 4.3).

These results are in agreement with previously reported findings in the literature (Jain and Khan, 2006; Jiang et al., 2017; Balaman et al., 2019) and collectively underscore the pronounced influence of scale on the economic viability of production systems.

Table 4.2 Overview of economic aspects of the menengiç manufacturing process in all scenarios (Q: 10,000 kg/batch)

Economic Aspects	Unit	Scenario 1 (A+B)	Scenario 2 (A+B+D)	Scenario 3 (A+B+C)	Scenario 4 (A+B+C+D)
<u>Simulation set parameters</u>					
Operation mode		**Batch**	**Batch**	**Batch**	**Batch**
Raw material processing size (Q)	kg RM/Batch	10000.00	10000.00	10000.00	10000.00
Annual operating time	day	300.00	300.00	300.00	300.00
Main Product Cost (MPC) (S-119.Total stream) *	$/kg MP	18.00	18.00	18.00	18.00
Animal supplementary material (ASM) (S-163. Total stream)	$/kg ASM	0.00	0.10	0.00	0.10
Menengiç oil (OIL) (S-111. Total stream)	$/kg OIL	5.67	5.67	5.67	5.67
Gold type instant menengiç powder (Gold) (S-124. Total stream)	$/kg GOLD	20.00	20.00	20.00	20.00
Ice cream (ICE) (S-145. Total stream)	$/kg ICE	0.00	0.00	1.23	1.23
Cone (CONE) (S-159. Total stream)	$/kg CONE	0.00	1.10	0.00	1.10
Raw Material Cost (RMC)	$/kg RM	4.20	4.20	4.20	4.20
Service Life (L)	y	20.00	20.00	20.00	20.00
Operating labor cost - basic rate (LC)	$/h	2.30	2.30	2.30	2.30
Raw material processing size (Q)	kg RM/y	72000000.00	72000000.00	72000000.00	72000000.00
Number of batch per year (Q)	#	599.00	599.00	598.00	598.00
<u>Material balance calculations</u>					
Unit Production Ref. Rate	kg MP/y	866967.00	866967.00	778968.00	778968.00

(MP) (S-119. Total stream)					
Animal supplementary material (ASM) (S-163. Total stream)	kg ASM/y	0.00	1684127.10	0.00	1681315.60
Menengiç oil (OIL) (S-111. Total stream)	kg OIL/y	3244152.50	3244152.50	3238736.50	3238736.50
Gold type instant menengiç powder (GOLD) (S-124. Total stream)	kg GOLD/y	216741.50	216741.80	216380.00	216380.00
Ice cream (ICE) (S-145. Total stream)	kg ICE/y	0.00	0.00	865519.80	865519.80
Cone (CONE) (S-159. Total stream)	kg CONE/y	0.00	609362.30	0.00000	607572.50
Yield for MP	kg MP/kg RM	0.01204	0.01204	0.01082	0.01082
Yield for ASM	kg ASM/kg RM	0.00000	0.02339	0.00000	0.02335
Yield for OIL	kg OIL/kg RM	0.04506	0.04506	0.04498	0.04498
Yield for GOLD	kg GOLD/kg RM	0.00301	0.00301	0.00301	0.00301
Yield for ICE	kg ICE/kg RM	0.00000	0.00000	0.01202	0.01202
Yield for CONE	kg CONE/kg RM	0.00000	0.00846	0.00000	0.00844
Capital Investment					
Total Capital Investment (TCI)	$	11013537.00	12016070.00	11975028.00	12977882.00
Purchased Equipment Cost (PC)	$	2298750.00	2553750.00	2537125.00	2792125.00
Direct Fix Capital (DFC)	$	7931947.00	8836330.00	8744248.00	9648631.00
Working Capital (30 days Operation) and Start-up Cost	$	2684993.00	2737924.00	2793568.00	2846820.00
Operating Cost					
Annual Operating Cost (AOC)	$/y	28825299.00	29551412.00	30164438.00	30889864.00
Operating Cost (OC)	$/batch	48122.00	49335.00	50442.00	51655.00

Revenues					
Total Revenues (TR=MR+OR)	$/y	38334590.00	34067413.00	37777245.00	37613707.00
Main Revenues (MR)	$/y	15605409.00	33787483.00	14021421.00	14021421.00
Other Revenues (OR), (GOLD, ASM, ICE, CONE, and/or OIL)	$/y	22729180.00	279930.00	23755824.00	24592286.00
Profits					
Unit Production Cost (UPC=AOC/MP)	$/kg MP	33.25	32.57	38.72	39.66
Gross Profit (GP=TR-OC)	$/y	9509000.00	9622000.00	7613000.00	7724000.00
Income Taxes (25%) (IT)	$/y	2377000.00	2405000.00	1903000.00	1931000.00
Annual depreciation charge (D)	$/y	754000.00	839000.00	830000.00	917000.00
Net Profit (NP=GP-T+D)	$/y	7886000.00	8056000.00	6540000.00	6710000.00
Unit investment cost (UIC=TCI/L*MP)	$/kg MP	0.64	0.69	0.77	0.83
Profitability Analysis					
Return on Investment (ROI=NP*100/TCI)	%	71.60	67.04	54.62	51.70
Payback Time (PBT=TCI/NP)	year	1.40	1.49	1.83	1.93
IRR (After Taxes)	%	51.51	48.46	39.67	37.72
NPV (at 7.0 % Interest)	$	46003000.00	46194322.00	35055811.00	35239182.00

* MP is Classic type instant menengiç powder

Table 4.3 Overview of the economic aspects of the change of production capacity in the 4th scenario of the menengiç production process.

Economic Aspects	**Unit**	**Scenario 4.1 (A+B+C+D)**	**Scenario 4.2 (A+B+C+D)**	**Scenario 4.3 (A+B+C+D)**
Simulation set parameters				
Operation mode		**Batch**	**Batch**	**Batch**
Raw material processing size (Q)	kg RM/batch	10000.00	7500.00	5000.00
Annual operating time	day	300.00	300.00	300.00
Main Product Cost (MPC) (S-119, Total stream) *	$/kg MP	18.00	18.00	18.00
Animal supplementary material (ASM) (S-163, Total stream)	$/kg ASM	0.10	0.10	0.10
Menengiç oil (OIL) (S-111, Total stream)	$/kg OIL	5.67	5.67	5.67
Gold type instant menengiç powder (Gold) (S-124, Total stream)	$/kg GOLD	20.00	20.00	20.00
Ice cream (ICE) (S-145, Total stream)	$/kg ICE	1.23	1.23	1.23
Cone (CONE) (S-159, Total stream)	$/kg CONE	1.10	1.10	1.10
Raw Material Cost (RMC)	$/kg RM	4.20	4.20	4.20
Service Life (L)	y	20.00	20.00	20.00
Operating labor cost - basic rate (LC)	$/h	2.30	2.30	2.30
Raw material processing size (Q)	kg RM/y	72000000.00	54000000.00	36000000.00
Number of batch per year (Q)	#	598.00	598.00	598.00
Material balance calculations				
Unit Production Ref. Rate (MP) (S-119, Total stream)	kg MP/y	778968.00	584226.00	389484.00
Animal supplementary material (ASM) (S-163, Total stream)	kg ASM/y	1681315.60	1260986.70	840657.80
Menengiç oil (OIL) (S-111, Total stream)	kg OIL/y	3238736.50	2429052.40	1619368.30
Gold type instant menengiç powder (GOLD) (S-124, Total stream)	kg GOLD/y	216380.00	162285.00	108190.00

Ice cream (ICE) (S-145, Total stream)	kg ICE/y	865519.80	649139.90	432759.90
Cone (CONE) (S-159, Total stream)	kg CONE/y	607572.50	456258.70	304172.50
Yield for MP	kg MP/kg RM	0.01082	0.01082	0.01082
Yield for ASM	kg ASM/kg RM	0.02335	0.02335	0.02335
Yield for OIL	kg OIL/kg RM	0.04498	0.04498	0.04498
Yield for GOLD	kg GOLD/kg RM	0.00301	0.00301	0.00301
Yield for ICE	kg ICE/kg RM	0.01202	0.01202	0.01202
Yield for CONE	kg CONE/kg RM	0.00844	0.00845	0.00845
Capital Investment				
Total Capital Investment (TCI)	$	12977882.00	11860366.00	9789287.00
Purchased Equipment Cost (PC)	$	2792125.00	2670875.00	2293563.00
Direct Fix Capital (DFC)	$	9648631.00	9218605.00	7880429.00
Working Capital (30 days Operation) and Start-up Cost	$	2846820.00	2180831.00	1514836.00
Operating Cost				
Annual Operating Cost (AOC)	$/y	30889864.00	24085863.00	17102404.00
Operating Cost (OC)	$/batch	51655.00	40270.00	28599.00
Revenues				
Total Revenues (TR=MR+OR)	$/y	37613707.00	28960917.00	19307278.00
Main Revenues (MR)	$/y	14021421.00	10516066.00	7010710.00
Other Revenues (OR), (GOLD, ASM, ICE, CONE, and/or OIL)	$/y	24592286.00	18444852.00	12296568.00
Profits				
Unit Production Cost (UPC=AOC/MP)	$/kg MP	39.66	41.23	43.91
Gross Profit (GP=TR-OC)	$/y	7724000.00	4875000.00	2205000.00

Income Taxes (25%) (IT)	$/y	1931000.00	1219000.00	551000.00
Annual depreciation charge (D)	$/y	917000.00	876000.00	748000.00
Net Profit (NP=GP-T+D)	$/y	6710000.00	4532000.00	2402000.00
Unit investment cost (UIC=TCI/L*MP)	$/kg MP	0.83	1.02	1.26
Profitability Analysis				
Return on Investment (ROI=NP*100/TCI)	%	51.70	38.21	24.54
Payback Time (PBT=TCI/NP)	year	1.93	2.62	4.07
IRR (After Taxes)	%	37.72	27.83	16.42
NPV (at 7.0 % Interest)	$	35239182.00	20474980.00	6981991.00

[a]*: DFC=Direct Cost (DC) + Indirect Cost (IC) + Other Cost (OC)*
Distributed set of PC-Factors:
DC=[1+0.25(piping)+0.1(instrumentation)+0.2(building)+0.1(electricity)+0.15(auxiliary)+0.1(others)]×PC
IC = 0.15×DC, OC=0.15×(DC+IC)
**Stream numbers in Figure 3.2*
* MP is Classic type instant nenengiç powder

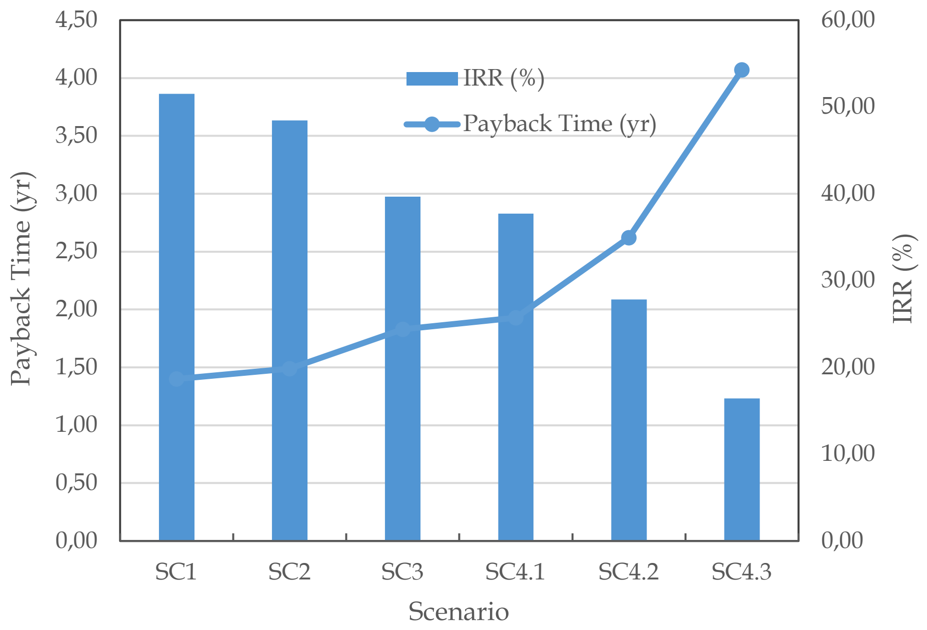

Figure 4.1 Profitability indices for all scenarios

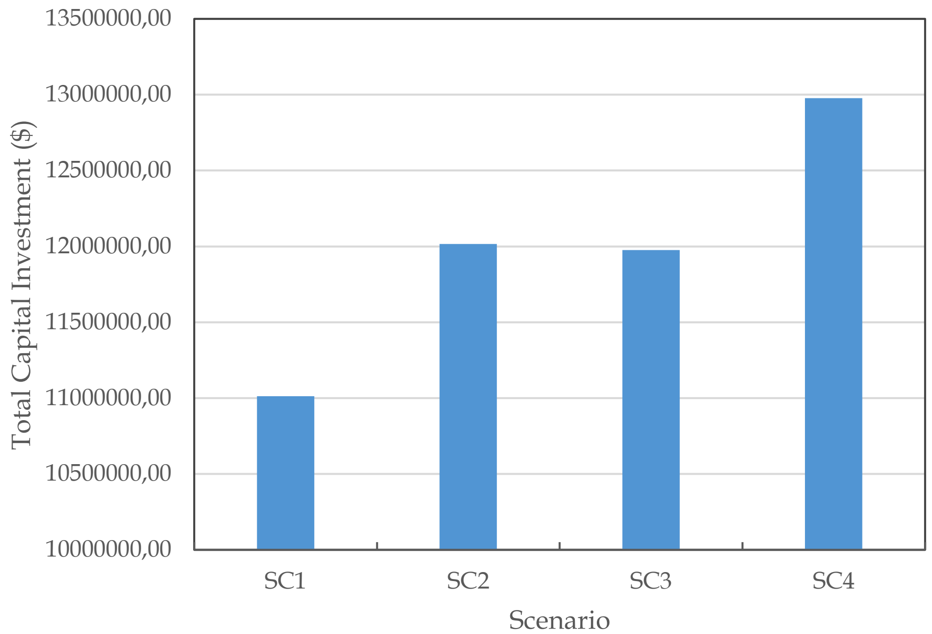

Figure 4.2 Total capital investments for all scenarios

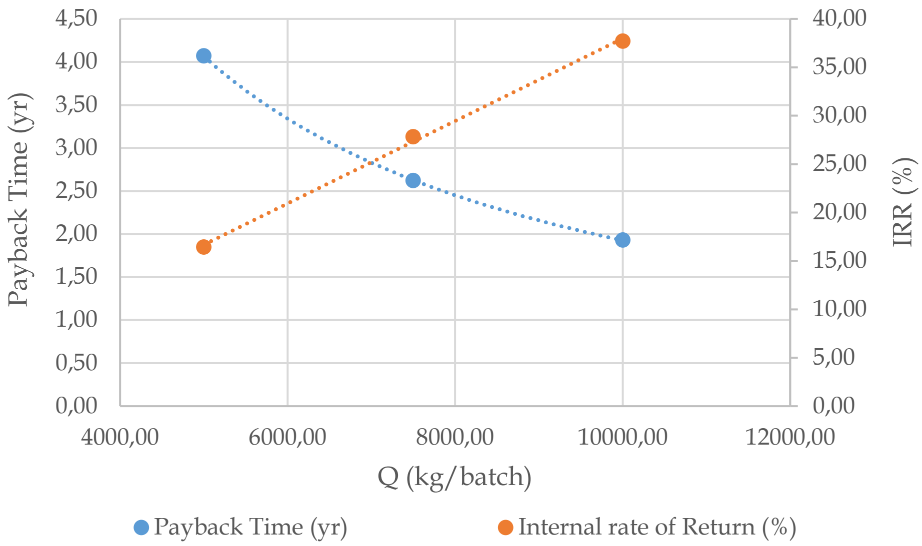

Figure 4.3 The effect of production capacity on profitability indices

CHAPTER 5
CONCLUSION

The production possibilities for menengiç oil, ice cream, cones, and animal feed support materials as by-products were assessed in this study, which established an integrated processing model based on the instant coffee production process from *Pistacia terebinthus* L. fruit. Technological and economic evaluations were carried out for various product distributions and production capacities, and an industrial-scale process simulation was carried out with a 10,000 kg/batch capacity.

The results of technological simulations show that 80% of the flow in the P-13 stage is allocated to the manufacture of classic tip coffee (778,968–866,967 kg annually) and 20% is allocated to the production of gold tip coffee (216,380–216,742 kg annually). In the P-10 phase, 90% of the flow is used for traditional coffee, while 10% is used for the manufacturing of ice cream (865,520 kg annually). Cone manufacture requires only 5% of the flow, allowing for an annual production of 607,573–1,017,299 kg. The manufacture of animal feed additives has reached a capacity of 1.68 million kg per year.

According to economic assessments, the total capital investment (TCI) in Scenario 1, which solely involves the production of coffee and oil, is USD 11.01 million, the internal rate of return (IRR) is 51.51%, and the payback period (PBT) is 1.40 years. The TCI is $12.98 million USD, the IRR is 37.72%, and the PBT is 1.93 years in Scenario 4, which incorporates all product flows. Since the cost of raw materials (4.20 USD/kg) makes up around 84% of the overall manufacturing cost, it is a crucial component of profitability.

The significance of economies of scale has been demonstrated by capacity analysis. At 10,000 kg/batch, the IRR was 37.72%; however, when the capacity was lowered to

7,500 kg/batch, it dropped to 27.83%, and at 5,000 kg/batch, it dropped to 16.42%. The payback durations, on the other hand, were determined to be 1.93, 2.62, and 4.07 years, respectively.

The findings show that processing menengiç fruit on an industrial scale is both economically viable and technically feasible, with profitability rising sharply at larger capacity. The study emphasizes the strategic significance of product diversity and scale optimization for investors and the food business in this regard.

REFERENCES

Akalın, A. S., Karagözlü, C., & Ünal, G. (2008). Rheological properties of reduced-fat and low-fat ice cream containing whey protein isolate and inulin. *European Food Research and Technology, 227*(3), 889–895. https://DOI:10.1007/s00217-007-0800-z

Arıoğlu, H., Yıldız, F., & Kaya, M. (2021). Functional compounds and potential health benefits of Pistacia terebinthus L. Food and Chemical Toxicology, 158, 112658.

Baggenstoss, J., Poisson, L., Kaegi, R., Perren, R., & Escher, F. (2008). Coffee roasting and aroma formation: Application of different time–temperature conditions. Journal of Agricultural and Food Chemistry, 56(14), 5836–5846. https://doi:10.1021/jf800327j

Bölek, S. (2018). Investigation of processing parameters for instant Pistacia terebinthus coffee (PhD dissertation, Gebze Technical University).

Bolek, S., & Özdemir, Y. (2017). Optimization of roasting conditions for Pistacia terebinthus using fluidized bed roaster. Journal of Food Processing and Preservation, 41(2), e12750. http://dx.doi.org/10.1016/j.lwt.2017.02.007

Bousbia, N., Vian, M. A., Ferhat, M. A., Petitcolas, E., Meklati, B. Y., & Chemat, F. (2009). Comparison of two isolation methods for essential oil from rosemary: Hydrodistillation and microwave hydrodiffusion and gravity. Food Chemistry, 114(1), 355–362. https://doi.org/10.1016/j.foodchem.2008.09.106

Bousbia, N., Djenane, D., & Chemat, F. (2021). Effect of High Temperature, Short Time (HTST) Pasteurization on Milk Quality Intended for Consumption. Journal of Dairying, Foods & Home Sciences 40(2):147-151. https://doi:10.18805/ajdfr.DR-210

Cruz, C., Fonte, C. P., Simone, A. D., Oppong, F. K., Jeatt, W., & Rodgers, T. L. (2022). Effect of homogenisation on fat droplets and viscosity of aged ice cream mixes. Chemical Engineering Science, 260, Article 117857. https://doi.org/10.1016/j.ces.2022.117857

Dahle, E., & Barnhart, H. M. (1931). Pasteurization and homogenization of cream and their effect on keeping quality. Journal of Dairy Science, 14(3), 195–207.Doğan, M., & Kayacier, A. (2007). The Effect of Ageing at a Low Temperature on the Rheological Properties of Kahramanmaras-Type Ice Cream Mix. International Journal of Food Properties, 10(1):19-24. https://doi.org/10.1080/10942910600610729

DURAK, M. Z, & UÇAK, G (2015). Solvent optimization and characterization of fatty acid profile and antimicrobial and antioxidant activities of Turkish Pistacia terebinthus L. extracts. Turkish Journal of Agriculture and Forestry 39 (1): 10-19. https://doi.org/10.3906/tar-1403-63

Durmaz, G., & Gökmen, V. (2011). Changes in oxidative stability, antioxidant capacity and phytochemical composition of Pistacia terebinthus oil with roasting. Food Chemistry, 128(2), 410–414. https://doi.org/10.1016/j.foodchem.2011.03.044

Dursun D, Koulouris A, Dalgıç AC (2020b) Process simulation and techno economic analysis of astaxanthin production from agro-industrial wastes. Waste Biomass Valori 11:943–954. DOI:10.1007/s12649-018-0439-y

Estévez-Sanchez, K. H., Ramos-Morales, M., Ruiz-Espinosa, H., Cortés-Zavaleta, O., García-Alvarado, M. A., Ochoa-Velasco, C. E., & Ruiz-Lopez, I. I. (2025). Effect of Particle Size Distribution on Mass Transfer During Solid-Fluid Extraction and Its Application to Coffee Brewing, Journal of Food Engineering 394:112511. https://doi.org/10.1016/j.jfoodeng.2025.112511

Eytemiş, A. (2016). A research of production potention of instant property coffee from terebinth (Pistacia terebinthus L.) seeds [Master's thesis, Kahramanmaraş Sütçü İmam University]. Council of Higher Education (YÖK) Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=HPPkMkIoHtKKAc7ZfgoVQ&no=ZM5mYh2vVKfrN3pES87ekg

Fatmawati, I., Nur'aini, R., & Karyantina, M. (2023). Ice Cream Cone Formulations From Wheat Flour and Tofu Dregs Flour Added With Beetroot (Beta Vulgaris L.) Extract. Agric 35, no. 1 (2023): 85–98.. https://doi.org/10.24246/AGRIC.2023.V35.I1.P85-98

Fidan, M. S., Baltacı, C., Öz, M., & Akar, Z. (2023). Chemical composition of Pistacia terebinthus L. and its phytochemical and biological properties. BioResources, 18(4), 6862–6881 https://doi.org/10.15376/biores.18.4.6862-6881

Fidan, H., Arıoğlu, H., & Kılıç, T. (2023). Valorization of Pistacia terebinthus L. fruit in functional dairy applications. Food Science and Technology International, 29(1), 55–64.

Food Science Journal. (2023). The role of roasting in coffee flavor development. FSJ Review Series, 29(1), 12–26.

López-Silva, M., & García-Valle, D. E. (2024). Ice cream cone fortified with spent coffee ground: Chemical composition, quality and sensory characteristics, and in vitro starch digestibility. Food Chemistry, 459, Article 140288 https://doi.org/10.1016/j.foodchem.2024.140288

Geçgel, Ü., & Arıcı, M. (2008). Çıtlık (Pistacia terebinthus L.) çeşitlerinin bazı fizikokimyasal özellikleri ile yağ asitleri kompozisyonunun belirlenmesi. Gıda Derneği,

Giraldo-Díaz, L. E., Escobar, L. M., & Rodríguez, A. M. (2023). Carbon footprint analysis of Colombian coffee production. Environmental Impact Assessment Review, 99, 106930.

Life Cycle Assessment (LCA) enables the quantification of environmental impacts and supports environmentally informed decision-making in process design.

Granger, C., Léger, A., Barey, P., Langendorff, V., & Cansell, M. (2005). Influence of formulation on the structural networks in ice cream. International Dairy Journal, 15(3), 255–262. https://doi.org/10.1016/j.idairyj.2004.07.009

Gülsoy, E., Başyiğit, G., & Öztürk, B. (2019). Chemical composition and functional properties of terebinth coffee (Pistacia terebinthus L.) powders. Journal of Food Processing and Preservation, 43(6), e13967.

Illy A, Viani R (2005) Espresso coffee: the science of quality, 2nd edn.Elsevier, London

Justiniano, N. K., Velásquez, M. L., Zenteno, F. G., & Rojas, M. L. (2022). Effect of Grinding and Sieving on the Coffee Properties: A Systematic Review. Paper presented at the 20th LACCEI International Multi-Conference for Engineering, Education and Technology, Boca Raton, Florida, USA. https://doi.org/10.18687/LACCEI2022.1.1.106

Karaoğul, E., Ugurtay, A., Kelley, S. S., & Alma, M. H. (2025). Modelling on extractions and micro nano encapsulation of Pistacia terebinthus cambium layer gum essential oil: Antioxidant activity and structural approach via XRD, SEM and TGA/DSC. Plant Foods for Human Nutrition, 80(1), 57. https://doi.org/10.1007/s11130-024-01274-8

Kavak, D. D., Altıok, E., Bayraktar, O., and Ülkü, S. (2010). "Pistacia terebinthus extract: As a potential antioxidant, antimicrobial and possible B-glucuronidase inhibitor," Journal of Molecular Catalysis B: Enzymatic 64(3-4), 167-171. DOI: 10.1016/j.molcatb.2010.01.029

Kavaz Yüksel, A., Şat, I. G., & Yüksel, M. (2015). The effect of terebinth (Pistacia terebinthus L.) coffee addition on the chemical and physical characteristics, colour values, organic acid profiles, mineral compositions and sensory properties of ice creams. Journal of Food Science and Technology, 52(12), 8023–8031. https://doi.org/10.1007/s13197-015-1904-2

Kaya, F., & Özer, A. (2020). A study on the investigation of diffusion coefficient for oil extraction from terebinth (Pistacia terebinthus L.) seeds. Current Physical Chemistry, 10(2), 144–153. https://doi.org/10.2174/1877946810666200129155312

Kekes, T., Koskinakis, S. E., Boukouvalas, C., & Krokida, M. (2025). Enhancing Environmental Sustainability in the Coffee Processing Industry via Energy Recovery and Optimization: A Life Cycle Assessment Case Study. Sustainability, 17(3), 1334. https://doi.org/10.3390/su17031334

Kekes, T., Georgiadis, M. C., & Papageorgiou, L. G. (2025). Energy and water optimization in coffee processing using waste heat recovery and ORC systems: An LCA approach. Sustainability, 17(3), 1456.

Konstantas, A., Stamford, L., & Azapagic, A. (2018). Environmental impacts of ice cream.Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2018.10.237

Kot, A., & Kamińska-Dwórznicka, A. (2024). Application of Ultrasound Homogenization in Milk Ice Cream Mixes. Applied Sciences, 14(19), 8689. https://doi.org/10.3390/app14198689.

Kozłowicz, K., Góral, M., Góral, D., Pankiewicz, U., & Bronowicka-Mielniczuk, U. (2019). Effect of ice cream storage on the physicochemical properties and survival of probiotic bacteria supplemented with zinc ions. *Journal of Dairy Science*, 102(9), 7835–7843. DOI:10.1016/j.lwt.2019.108562

Kwakye, M., Darko, C., & Aidoo, R. (2021). Comparative life cycle assessment of freeze-dried and spray-dried coffee. Environmental Sustainability, 4(3), 357–365.

Lashmanova, L., Ibragimova, R., & Borisova, A. (2024). Influence of coffee brewing methods on organoleptic and physico-chemical properties. Bulletin of KSAU, 3, 181–187. https://doi.org/10.36718/1819-4036-2023-3-181-187

Machado, F., Duarte, R. V., Pinto, C. A., Casal, S., Lopes-da-Silva, J. A., & Saraiva, J. A. (2023). High Pressure and Pasteurization Effects on Dairy Cream. Foods, 12(19), 3640. https://doi.org/10.3390/foods12193640

Mahulkar, K. C., Patil, A., Bhalerao, P. P., Dabade, A., Hundare, S., Bhushette, P., & Sonawane, S. K. (2024). Optimization of formulation millets flours for waffle ice cream cone using simplex lattice design: Characterization and shelf life study. Food Chemistry Advances, 4, Article 100600. https://doi.org/10.1016/j.focha.2023.100600

Maroulis, Z. B., & Saravacos, G. D. (2003). Food Process Design. CRC Press.

Misailidis, N., Pérez Sánchez, A., & Petrides, D. (2022, August). Ice cream production – Process modeling and techno-economic assessment (TEA) using SuperPro Designer® [Intelligen, In http://dx.doi.org/10.13140/RG.2.2.27365.06881

Mohammed, H., Al-Juhaimi, F., & Ghafoor, K. (2023). Utilization of spent coffee grounds in ice cream cone formulations: Effects on nutritional and sensory quality. Journal of Food Processing and Preservation, 47(3), e16091.

Muzykiewicz-Szymańska, A., Nowak, A., Wira, D., & Klimowicz, A. (2021). The effect of brewing process parameters on antioxidant activity and caffeine content in infusions of roasted and unroasted Arabica coffee beans originated from different countries. Molecules, 26(12), 3681. https://doi.org/10.3390/molecules26123681

Muse, M. R., & Hartel, R. W. (2004). Ice cream structural elements that affect melting rate and hardness. Journal of Dairy Science, 87(1), 1–10.https://doi.org/10.3168/jds.S0022-0302(04)73135-5

Özcan M (2004) Characteristics of fruit and oil of terebinth (Pistaciaterebinthus L.) growing wild in Turkey. J Sci Food Agr 84:517–552.

Özcan, M. M., Al Juhaimi, F., Uslu, N., Ahmed, I. A. M., Babiker, E. E., Osman, M. A., Gassem, M. A., Alqah, H. A. S., & Ghafoor, K. (2020). Effect of sonication process of terebinth (Pistacia terebinthus L.) fruits on antioxidant activity, phenolic compounds, fatty acids and tocopherol contents. Journal of Food Science and Technology, 57(6), 2017–2025. https://doi.org/10.1007/s13197-019-04235-1

Patel, A., Lakhera, N., & Sarda, A. (2013). Thermal optimization of an ice cream hardening process. International Journal of Food Engineering, 9(4), 401–410. https://doi.org/10.1515/ijfe-2012-0215

Pazmiño, M. L., Mero-Benavides, M., Avilés, D., Blanco-Marigorta, A. M., Tinoco, D. L., & Ramírez, Á. D. (2022). Life cycle assessment of instant coffee production considering different energy sources. Journal of Cleaner Production, 366, 132949.

Peters MS, Timmerhaus KD (1991) Plant design and economics for chemical engineers. McGraw-Hill, New York.

Peters, M. S., & Timmerhaus, K. D. (1991). Plant Design and Economics for Chemical Engineers (5th ed.). McGrawHill.

Poyrazoğlu, E. S., Temel Özat, E., Coksarı, G., Özat, E., & Konar, N. (2017). Effect of various process conditions on efficiency and colour properties of Pistacia terebinthus oil encapsulated by spray drying. International Journal of Food Engineering, 3(2), 132–135. https://doi.org/10.18178/ijfe.3.2.132-135

Ratanasanya, S., Chindapan, N., Polvichai, J., Sirinaovakul, B., & Devahastin, S. (2022). Model-based optimization of coffee roasting process: Model development, prediction, optimization and application to upgrading of Robusta coffee beans. Journal of Food Engineering, 328, 111100.

Seçilmiş, C., & Göğüş, F. (2014). Aroma and sensory evaluation of roasted Pistacia terebinthus oils. Food Science and Biotechnology, 23(4), 1125–1130.

Singh, S. P., Gaikwad, K. K., & Lee, Y. S. (2021). Simulation in food manufacturing: Tools and applications. Trends in Food Science & Technology, 112, 198–210.

Sür A, Eyiler Kaya E, Vural H. Pistacia terebinthus L. oil extraction by liquid and supercritical carbon dioxide modified with a co-solvent and evaluation of phenolic compounds, fatty acids profile and tocopherols. *Gıda*. 2024;49(3):397–407. https://doi.org/10.15237/gida.GD23132

Syed, Q. A., Anwar, S., Shukat, R., & Zahoor, T. (2018). Effects of different ingredients on texture of ice cream. *Journal of Nutritional Health & Food Engineering, 8*(6), 422–435. https://doi.org/10.15406/jnhfe.2018.08.00305

Tosaki, M., Kitamura, Y., Satake, T., & Tsurutani, T. (2009). Effects of homogenisation conditions on the physical properties of high-fat ice cream. International Journal of Dairy Technology, 62(4), 577–583. https://doi.org/10.1111/j.1471-0307.2009.00525.x

Tvorogova, A. A., Sitnikova, P. B., Shobanova, T. V., & Zakirova, R. R. (2020). Research of the effect of aging process on dispersion of air phase and ice crystals in milk ice cream. Food Systems, 3(2), 14–17. DOI:10.21323/2618-9771-2020-3-2-14-1

Vaia. (2023). Coffee chemistry. Vaia Learning Platform. https://www.vaia.com/en-us/explanations/nutrition-and-food-science/food-chemistry/coffee-chemistry/

Vezzulli, F., Lambri, M., & Bertuzzi, T. (2023). Volatile compounds in green and roasted Arabica specialty coffee: Discrimination of origins, post-harvesting processes, and roasting level. Foods, 12(3), 489. https://doi.org/10.3390/foods12030489

Voronin, G. L., Ning, G., Coupland, J. N., Roberts, R., & Harte, F. M. (2021). Freezing kinetics and microstructure of ice cream from high-pressure-jet processing of ice cream mix. *Journal of Dairy Science, 104*(3), 2843–2854. https://doi.org/10.3168/jds.2020-19011

Wintgens, J.N. (2004) Coffee: Growing, Processing, Sustainable Production. A guide for growers, traders, and researchers. WILEY-VCH Verlag GmbH and Co.KGaA, Weinheim, Germany.

Worku, M., Aerts, R., & Muys, B. (2018). Environmental and socioeconomic determinants of forest coffee yield variability in southwestern Ethiopia. Forest Ecology and Management, 409, 238-247.

Yaman, D. M., Koçak Yanık, D., Elik Demir, A., Uzun Karka, H., Güçlü, G., Selli, S., Kelebek, H., & Göğüş, F. (2023). Effect of encapsulation techniques on aroma retention of Pistacia terebinthus L. fruit oil: Spray drying, spray freeze drying, and freeze drying. Foods, 12(17), Article 3244. https://doi.org/10.3390/foods12173244

CURRICULUM VITAE

PERSONEL INFORMATION

Name Surname: Zahide ERCAN

ACADEMIC QUALIFICATIONS

Gaziantep University – MSc in Food Technology (Thesis, English) 2022- Present
Institute of Natural Sciences – Department of Food Engineering

Gaziantep University – BSc in Food Engineering (English) 2015 - 2020
Faculty of Engineering

JOB EXPERIENCE

Quality Responsible
Akanlar Çikolata, Gaziantep, Türkiye
Nov. 2024 – Present

R&D Responsible
ŞEKEROĞLU GROUP GIDA SAN. ve TİC. A.Ş., Gaziantep, Türkiye
Oct. 2022 – Sep. 2024

I have been working as an R&D Supervisor, ensuring the improvement of existing products and preparing projects for production applicability. My responsibilities include conducting product trials based on customer demands, developing and formulating new products, performing pilot-scale trials, and reporting analytical results. I monitor and report shelf-life studies of existing products and manage quality control activities for raw material acceptance, in-process, and final products. In addition, I carry out alternative raw material and supplier evaluation studies, conduct sensory and application trials for innovative product development, and ensure compliance of products and processes with legal regulations.

Production and Quality Engineer

ARYA NUTS Gıda Lojistik İnş. Otomotiv İç ve Dış Tic. Ltd. Şti., Gaziantep, Türkiye

February 2021 – October 2022

In this role, I was responsible for managing daily production and quality control activities, performing raw material acceptance and control, and designing process lines for new product groups. I prepared and reported production and quality data, while also ensuring the implementation of hygiene and sanitation procedures across the production facility.

Intern Food Engineer

ŞÖLEN Çikolata Gıda San. ve Tic. A.Ş., Gaziantep, Türkiye

February 2020 – March 2020

CONGRESS AND TRAININGS

14th Food Engineering Student Congress, 12–13 May 2025, Çukurova University, Adana, Turkey – Poster Presentation

"Production of Instant Coffee and Alternative Products from Pistacia terebinthus L. Fruit: Establishment of Process Models of Production"

Graduate Student, Department of Food Engineering, Gaziantep University