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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

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OPTIMIZATION OF SPRAY-DRYING PROCESSING CONDITIONS ON PHYSICOCHEMICAL AND SENSORY PROPERTIES OF INSTANT PAPAYA (*Carica papaya L.*) POWDER

By

Meseret Snshaw

Advisor: Dr. Addisalem Hailu (Associate prof)

JUNE 2026

Addis Ababa, Ethiopia

Optimization of Spray-Drying Processing Conditions on Physicochemical and Sensory Properties of Instant Papaya (Carica Papaya L.) Powder

A THESIS SUBMITTED TO POSTGRADUATE STUDY IN PARTIAL FULFILMENT OF THE DEGREE OF MASTER OF SCIENCE IN FRUIT AND VEGETABLE PROCESSING TECHNOLOGY

By

Meseret Snshaw

Advisor: Dr. Addisalem Hailu (Associate prof)

JUNE, 2026

Addis Ababa, Ethiopia

DECLARATION

I earnestly declare that this thesis is my work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Federal TVET Institute and is deposited at the Institute's Library to be made available to borrowers under rules and regulations of Institute and the country. I declare with certainty that this thesis is not submitted to any institution, bureau, anywhere for the award of any academic degree, diploma, or certificate.

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This is to certify that the the above declaration is made by the candidate is correct to the best of my knowledge.

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OPTIMIZATION OF SPRAY-DRYING PROCESSING CONDITIONS ON PHYSICOCHEMICAL AND SENSORY PROPERTIES OF INSTANT PAPAYA (CARICA PAPAYA L.) POWDER

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BIOGRAPHICAL SKETCH

The author, Meseret Snshaw, was born to his father, Mr. Snshaw Mgbaru, and his mother, Mrs. Teyeku Kelkay, on December 12, 1986 (EC) in Merawi city, West Gojjam Zone of the Amhara Regional State, Ethiopia. He attended his elementary education at Zeleke Desta Elementary and Junior School from 1995 to 2002 (EC). Then, he completed his secondary education at Abay Minch Secondary School from 2002 to 2003 (EC). He joined Alage Agricultural College in November 2004 and graduated with an Advanced Diploma in Plant Science in January 2006 (EC).

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During conducting of this research work, I have met a lot of people outside and inside the work atmosphere that contributed to make this adventure possible and enjoyable. I would like to use the opportunity to acknowledge all those who have made possible the completion of the study.

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ABBREVIATIONS AND ACRONYM

ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemists
aw	Water Activity
BBD	Box-Behnken Design
BD	Bulk Density
FAO	Food and Agriculture Organization
FR	Feed Rate
FS	Fan Speed
FTI	Federal TVET Institution
HSD	Honestly Significant Difference
IT	In let Temperature
MARC	Melkasa Agricultural Research center
mL	Milliliter
mL/min	Milliliter per minute
OHC	oil holding capacity
PG	polygalacturonase
pH	Potential of Hydrogen
PME	pectin methyl esterase
RH	Relative Humidity
RSM	Response Surface Methodology
S/g	second per Gram
SPSS	Statistical Package for the Social Sciences
TSS	Total soluble Solids
ULD	Ultra Lower Adapter
W/V	Weight per Volume
WHC	water holding capacity

ABSTRACT

This study was conducted to optimize spray-drying process conditions for the production of high-quality instant papaya powder from the 'Red Lady' papaya variety and to evaluate its physicochemical and sensory properties. Response Surface Methodology (RSM) based on a three-factor, three-level Box–Behnken Design (BBD) was employed to investigate the effects of inlet air temperature (150–180°C), feed flow rate (6–10 mL/min), and fan speed (60–80%) on product quality attributes. The evaluated responses included process yield, moisture content, water activity (aw), bulk density, water holding capacity (WHC), oil holding capacity (OHC), solubility, total soluble solids (TSS), viscosity, pH, and sensory characteristics. The results showed that spray-drying conditions significantly ($p < 0.05$) affected most physicochemical and sensory properties of the powder, with inlet air temperature and feed flow rate being the most influential factors. Across the experimental runs, process yield ranged from 65.10% to 81.93%, moisture content from 2.77% to 5.27%, water activity from 0.31 to 0.48, bulk density from 0.28 to 0.34 g/mL, solubility from 83.67% to 89.17%, and overall acceptability from 6.06 to 7.22 on a 9-point hedonic scale. Numerical optimization identified the optimal spray-drying conditions as an inlet air temperature of 170.9°C, a feed flow rate of 7 mL/min, and a fan speed of 63%, with an overall desirability value of 0.818. Under these conditions, the model predicted a process yield of 79%, moisture content of 3.22%, water activity of 0.34, bulk density of 0.29 g/mL, solubility of 85.7%, and overall acceptability of 7.2. Validation experiments produced values of 82.0% process yield, 2.8% moisture content, water activity of 0.31, 86.2% solubility, and an overall acceptability score of 7.22, confirming the adequacy of the developed models. The findings demonstrated that spray drying with 15% (w/w) maltodextrin is an effective preservation technique for producing stable, functional, and consumer-acceptable instant papaya powder suitable for beverage and food applications.

***Keywords**: Box–Behnken Design, instant papaya powder, optimization, physicochemical properties, Response Surface Methodology, sensory evaluation, spray drying.*

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CHAPTER ONE

1 INTRODUCTION

1.1 Background

Papaya (*Carica papaya L*.) is a very wholesome and inexpensive tropical fruit that is available all the time regardless of the weather and season(Ahmad *et al*., 2013). It is highly appreciated around the world for its flavour, nutritional quality and digestive properties(Aravind *et al*., 2013). Regular consumption of papaya is able to ensure sufficient amount of vitamins (A, B2 and C) and minerals (folate, calcium, thiamine, iron, niacin, and potassium) (Gemeda *et al*., 2025). Global papaya production has seen substantial growth over the last few decades, transitioning from a localized tropical fruit to a major global commodity. According to historical metrics synthesized by (González-Oviedo *et al*., 2025), the global cultivation area for papaya expanded dramatically from 114,192 hectares in 1961 to over 438,239 hectares by the 2010s. This steady agricultural expansion has pushed contemporary yields to millions of metric tons annually, with developing countries driving the majority of this immense output. Ultimately, this massive volume of highly perishable fresh produce underscores the urgent economic and industrial need for advanced preservation methods, such as spray drying, to minimize severe post-harvest losses.

Papaya has been grown in a number of nations for both domestic and international markets. In 2010, the global papaya production was estimated to be between 11 and 22 million metric tons. Between 2008 and 2010, Asia accounted for roughly 52–55 percent of the world's papaya production, followed by South America (23–09 percent) and Africa (13–16 percent). (Ayele *et al*., 2017).It was one of the economically significant fruits cultivated throughout Ethiopia. For domestic consumption and the local market, farmers grew it in home gardens and at semi-commercial levels (Fikadu & Etissa, 2025). It is noteworthy that the regional states of Ethiopia have been extensively involved in the cultivation of papayas, with a substantial count of 15,572,313 households participating. During the interval of 2011 to 2015, the land utilized for papaya production underwent a marked progression, increasing from 22,262.52 to 40,435.06 hectares, translating to an 81.6 percent expansion over the said period (Fikadu & Etissa, 2025). In terms of its nutritional and medicinal properties, Papaya, a

tropical fruit, stands out as a vibrant and essential element in the tapestry of the dietary landscape. Consisting primarily of water (85%), intermediate levels of sugar (10-13%), protein (0.6%), and an abundance of Vitamins B1, B2, and C, it is a significant component in one's diet. Research endeavors focused on drying papayas utilizing the freeze-drying, solar drying, and a hot air oven methods (Athmaselvi *et al*., 2014). There aren't many studies on the production of spray-dried papaya powder, and the process of making it increases the number of potential applications for papaya powder in the food industry. Recent studies show that papaya post-production losses, particularly in developing countries, can range from 25 to 40 percent (Gunathilake *et al*., 2018).

According to research, dehydration reduces the water activity of fruits, which inhibits microbial growth and enzymatic activity. Other methods of fruit preservation include foam-mat drying, freeze-drying, and hot air ovens. Papaya powder was produced by solar drying, although there have been few studies on the use of spray drying (C.-L. Chang *et al*., 2020). Because of its low cost and rapid drying speed, Spray drying is among the most popular processing techniques for producing powder in liquid foods (Tamime, 2009). Juice can be dehydrated into powder by spray drying, which prolongs its shelf life. The dry air properties, the kind of carrier agent, the way hot air interacts with droplets in the chamber, and the spray drying scale all affect the quality of the powder that is produced (D. Q. Nguyen *et al*., 2022). Compared to other drying techniques, a product can be dried with a spray dryer much faster and are ideal for heat-sensitive products because of their brief exposure to high temperatures. Spray-drying is a continuous process that combines a number of states, including atomization, spray diffusion in air, evaporation, and product separation, to turn a fluid (solution, dispersion, or emulsion) into dry particles (Castañón Rodr\'\iguez *et al*., 2020).

1.2 Problem statements

In Ethiopia, papaya is widely cultivated and mainly consumed in its fresh form, with limited value addition and industrial processing. As a result, a considerable portion of the harvest is lost due to its high perishability, seasonal availability, and inadequate post-harvest handling and preservation techniques. Currently, traditional processing methods such as sun drying and simple juice preparation are commonly practiced; however, these methods often lead to significant losses in nutritional quality, flavor, and overall product acceptability. In contrast,

advanced dehydration techniques such as spray drying, which are widely used in food industries globally to produce stable instant fruit powders, are not well developed or optimized in the Ethiopian context (Hinostroza-Quiñonez *et al*., 2024).

Despite the potential of papaya as a raw material for value-added products, there is a lack of scientific studies in Ethiopia focusing on the optimization of spray-drying process parameters such as inlet air temperature, feed flow rate, and fan speed for papaya powder production. In addition, limited information is available on the physicochemical and sensory properties of spray-dried papaya powder and how these quality attributes are influenced by processing conditions. Furthermore, there is no standardized processing framework for producing instant papaya powder using modern drying technologies, and most existing studies in the country focus on conventional drying methods rather than advanced techniques like spray drying combined with statistical optimization tools such as response surface methodology (RSM), (Hinostroza-Quiñonez *et al*., 2024).

Therefore, this study addresses these gaps by optimizing spray-drying process conditions for the production of high-quality instant papaya powder with desirable physicochemical and sensory attributes. The findings are expected to contribute to reducing post-harvest losses, improving value addition, and promoting the development of fruit-based instant products in Ethiopia.

1.3 Objectives

1.3.1 General Objective

The general objective of this research is to optimize the spray-drying process conditions for the production of high-quality instant papaya powder with desirable physicochemical and sensory attributes.

1.3.2 Specific Objectives

- To optimize spray-drying processing conditions for producing instant papaya powder and validate the optimized conditions.
- To characterize the desirable quality attributes (physicochemical properties) of instant papaya powder.
- To evaluate the sensory properties of instant papaya powder.

1.4 Research Questions

1. How do inlet air temperature, feed flow rate, and fan speed affect the physicochemical properties of instant papaya powder?
2. How do inlet air temperature, feed flow rate, and fan speed affect the sensory properties of instant papaya powder?
3. What are the optimal spray-drying conditions for producing instant papaya powder with desirable physicochemical and sensory attributes?

1.5 Hypothesis of the research

Null Hypothesis (H_0): There is no significant effect of inlet air temperature, feed flow rate, and fan speed on the physicochemical and sensory properties of instant papaya powder, and there is no optimal combination of these parameters for producing high-quality powder.

Alternative Hypothesis (H_1): There is a significant effect of inlet air temperature, feed flow rate, and fan speed on the physicochemical and sensory properties of instant papaya powder, and an optimal combination of these parameters exists for producing high-quality instant papaya powder.

1.6 Significance of the research

This study is significant as it contributes to the development and optimization of spray-drying technology for the production of instant papaya powder. In Ethiopia, papaya is widely produced but mainly consumed in fresh form, resulting in considerable post-harvest losses due to its high perishability. Therefore, optimizing spray-drying conditions offers a practical approach for value addition and improved preservation of papaya (Ueda *et al*., 2023).

The study provides scientific information on the relationship between key spray-drying parameters (inlet air temperature, feed flow rate, and fan speed) and the physicochemical and sensory qualities of instant papaya powder. This will support the identification of optimal processing conditions for producing a stable, high-quality, and consumer-acceptable product (Watson *et al*., 2018).

The research is expected to enhance product quality attributes such as solubility, water absorption capacity, appearance, flavor, and aroma, which contribute to consumer satisfaction. In addition, optimized spray-drying conditions can improve powder stability and

shelf life by reducing moisture content and limiting microbial growth, thereby supporting food safety and reducing food waste (Jadhav *et al*., 2024).

Furthermore, instant papaya powder has potential applications in various markets, including health foods, nutritional supplements, and culinary uses. The study provides useful data for developing instant fruit-based powders, contributing to food diversification, nutritional improvement, and reducing dependence on imported powdered products. It also promotes the utilization of locally available fruits for industrial processing and encourages innovation in food processing technology (Tetteh, 2022)**.**

1.7 Scope of the research

This study focuses on the optimization of spray-drying process conditions for the production of instant papaya powder. It specifically considers three independent variables: inlet air temperature, feed flow rate, and fan speed, and evaluates their effects on the quality of the final product using Response Surface Methodology (RSM). The quality assessment of the instant papaya powder is limited to selected physicochemical properties, including moisture-related characteristics, solubility, and texture-related parameters, as well as sensory attributes of the reconstituted product such as color, flavor, and aroma. The study does not include other drying techniques such as freeze-drying or tray drying and is restricted to laboratory-scale spray-drying experiments.

In addition, the study does not cover industrial-scale production or commercialization aspects; however, it provides useful baseline data that can support future scale-up and industrial applications. The study does not include storage stability studies and microbial quality due to insufficient funding. The raw material used in this research is limited to ripe papaya fruits; therefore, other fruit varieties are not included. As a result, the findings are specific to papaya and may not be directly generalized to other fruits without further investigation.

1.8 Organization of the Thesis

This thesis is organized into five chapters.

The **first chapter** presents the introduction of the study, including background information, statement of the problem, objectives, research questions, significance of the study, scope, and limitations of the research.

The second chapter provides a review of related literature on papaya production and utilization, post-harvest physiology and biochemistry, post-harvest handling practices, and an overview of spray drying technology. It also covers Response Surface Methodology (RSM) and Box–Behnken Design (BBD) as optimization tools applied in food processing studies.

The **third chapter** describes the materials and methods used in the study. It includes the experimental location, raw materials, equipment and instruments, sample preparation procedures, spray drying process, experimental design using RSM-BBD, and analytical methods used for evaluating physicochemical, functional, and sensory properties of spray-dried papaya powder.

The **fourth chapter** presents the results and discussion of the study. It includes the effects of process variables on product quality, statistical analysis using ANOVA, model development, optimization of spray-drying conditions, and validation of predicted and experimental results.

The **fifth chapter** provides the conclusions and recommendations based on the findings of the study, along with suggestions for future research and potential applications.

The thesis also includes references and appendices, which provide supporting materials and a list of all sources cited in the study.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 General overview of papaya fruit

The papaya tree is similar to a plant with a single, hollow stem, bearing leaves and fruit at its apex. It originated in Central America and expanded to South America and other regions during the sixteenth century. There are three primary plant varieties: male, female, and hermaphrodite. Only the female and hermaphrodite plants yield fruit; the males merely produce pollen. Pollination of female plants relies on insects and wind, while hermaphrodite plants are capable of self-pollination. Papaya is a climacteric fleshy fruit, notable for its swift ripening post-harvest. After being picked, papaya fruits undergo quick metabolic changes, resulting in increased sweetness and softening. Consequently, the post-harvest losses of farmers' papaya produce offer several opportunities to enhance profitability by increasing the value of local products, improving bargaining power, expanding access to markets, and encouraging more competition among growers (Milkias & Degefu, 2024).In fact, Improper post-harvest handling and unsuitable treatment techniques during harvesting, marketing, transportation, and storage lead to post-harvest losses. Thus, preserving and increasing the quantity of harvested fruits and vegetables largely relies on effective post-harvest practices. However, in Ethiopia, farmers and traders make limited use of agricultural practices and technology (Hunde, 2017).

2.2 Papaya production and utilization

Papaya is a widely enjoyed fruit found in tropical and subtropical regions, known for its health benefits and nutritional value. It is currently classified within the Caricaceae plant family, which includes 35 species that produce latex and fall into four genera: Carica, Jarilla, Jacaratia, and Cyclicomorpha (Burns *et al*., 2022). In the past, it was grouped under the Passifloraceae, Bixaceae, Cucurbitaceae, and Papayaceae families. Papaya originates from southern Mexico, the Philippines, and Central America(Gil & PESQUEIRA, 2023) and names India, Mexico, Brazil, Indonesia, and Nigeria among the leading producers. Papaya has a huge export market in the global trade of tropical fruits due to its excellent nutritional content (Koul *et al*., 2022). After mango and pineapple, papaya is presently placed third with

15.36% of total tropical fruit output. Papaya has a global production of 13.4 million metric tons. India's production capacity is 6.39 million metric tons. On the basis of state-by-state value of papaya production, Andhra Pradesh is the first major producer and Gujarat is the second largest (Fitch, 2020).

Many bioactive components found in papaya, including carotenoids, phenolic compounds, vitamins A, C, and E, pantothenic acid, minerals (potassium and magnesium), folate, and fiber, have several positive health benefits on the body that are attributed to their ant oxidation characteristics (Koul *et al.*, 2022). Based on nutritional evaluations, papaya is ranked among the top five fruits, with watermelon, kiwi, guava and apple (Alara *et al*., 2020).

Processing of papaya results in the production of 6.51% of seeds, 8.47% of skin, 32% of pulp, which is unusable, and 52.96% of finished products (Patra *et al*., 2024). The production of such significant volumes of waste material shows that the value addition of all these by products would greatly benefit to papaya growers. Characterizing the various ripe and unripe papaya parts, along with their peels and seeds, is a useful approach to show that their complete usage may provide vital elements including vitamins and bioactive substances (Tasmin, 2023). Carotenoids, phenolic acids, and flavonoids are the principal bioactive compounds found in papaya pulp, skin, and seeds, respectively (Ovando-Martínez & González-Aguilar, 2020).

2.3 Nutritional compositions of papaya fruit and phytochemical profile

Papaya contains relatively high levels of vitamins A, B1, B and C (Koul *et al*., 2022). The papaya fruit is also known to be an excellent source of glucose, fructose and sucrose (Koul *et al*., 2022). Presented the nutritional composition of Rainbow papaya which was the first commercialized transgenic fruit crop (Ranganath, 2022) showed that esterified xanthophylls such as β-cryptoxanthin laurate and caprate were the most abundant pigments during incipient carotenoid biosynthesis during the developmental stage of papaya fruit. The result indicated that the building up of caro tenoids such as β-cryptoxanthin laurate and total lycopene contents positively correlates with a subsequent fruit maturation. On the other hand, the papaya aroma is principally due to esters, where ethyl butanoate, ethyl acetate, ethyl hexaonate and ethyl 2-methyl butanoate are the most potent odor compounds. Papaya is also

considered as a functional food fruit since consumption of ripe papaya fruit has been associated with a curing effect to a certain diseases. For example, (Riram *et al*., 2024) reported that from a pharmacological point of view, the papaya has been cited as a laxative, antifertility agent, and meat tenderizer, among other uses.

The nutritional profile can be affected by processing methods, making it essential to optimize drying conditions to retain these beneficial components (Pérez-Jiménez & Saura-Calixto, 2017).

According to the papaya's chemical analysis, it contains significant quantities of sodium, calcium, phosphorus, zinc, iron, copper, magnesium, and manganese (as shown in Table 2.1.1). Additionally, it has detectable quantities of potassium, with a measurement of 223 mg per 100 grams of fresh fruit. In terms of vitamin A, C, B1, B2, thiamine, folate, niacin, riboflavin, calcium, iron, potassium, and fiber content, papaya has a prominent position among fruits. It is high in vitamins and minerals yet low in calories. For 100 g of fruit, around 60% of the mature fruit is edible. Papaya has an energy content of 200 kJ/100 g. The three primary sugars are sucrose (48.3 g/100 g), fructose (21.9), and glucose (29.8 g/100 g). Ascorbic acid content in fresh fruit is around 108 mg/100 g, which is greater than oranges with content of 67 mg/100 g (Koul et al., 2022).

Table 1: Nutritional value in papaya fruits, seeds, and leaf (mg/100 g)

Parameter	Fruit	Seed	Leaf
Moisture(%)	84.32-90.76	2.30-9.73	58.5-64.10
Ash (%)	0.27-0.38	6.84-10.7	1.87-11.20
Carbohydrate (%)	7.66-13.54	8.3-26.6	10.47-58.40
Protein (%)	0.37-0.45	24.3-31.80	16.08-29.50
Lipid (%)	0.20-0.29	20.97-30.1	2.70-6.31
Dietary fiber (%) 0	0.37-0.60	17.0-22.6	1.27-2.13
β-carotene (µg/g)	208.67-4534.26	888.00	-
Ascorbic acid (mg/g)	35.32-43.80	0.12-0.15	126.2
Na	6.79-9.53 g/kg	39.80 g/kg	0.03 g/kg

K	18.36-24.78	743.30-1635.50	2.75
Fe	Fe 0.61-0.85	5.23-5.80	0.46-1.84
Ca	27.88-32.48	725.00-8435.10	4.80-32.73
Zn	-	5.00-6.17	0.04-0.05
P	11.54-16.81	566.9	-
Cu	-	0.50-1.09	0.01-0.06
Mn	-	2.50-3.10	0.12-0.66
Mg	9.45-13.63	218.80-332.50	16.18

Source: (Dotto & Chacha, 2020) and (Tasmin, 2023)

2.4 Concepts of Papaya handling Practices

The deliberate act of separating the food material from the positioning of immediate growth or production, for instance, the reaping of papaya, the picking of fruits, the lifting of fish from the water, etc. was termed harvesting (FAO, 2018). Harvesting was accomplished by hand, mechanically assisted picking devices or mechanical harvester's robotics which offers the long-term potential of blending the efficiency of machines with the selectivity of humans. Factors during harvesting operations that would influence post-harvest quality include the degree of severity of mechanical damage induced by machines or humans, the accuracy of selecting acceptable rather than unacceptable fruit, the time of day of harvest and so the pulp temperature at harvest (Prusky, 2011). Post-harvest started when the tactic of collecting or trying out edible quality food from its site of immediate production has done. Post-harvest began at the moment of separation of the edible product from the plant by a deliberate human act that started it farm to the table.

Papaya harvesting systems had a period of production, a time for harvest, an occasion for transportation, where gathering, packaging, or selection occurs. Moreover, several periods of short or future storage; and a stage where food is distributed to the consumers, pre-harvest drying, transport, post-harvest drying, threshing, storage, processing, and marketing where necessary. Keeping with this, the time of harvesting was set by the degree of maturity.

Among fruits, a difference made between the maturity of stalks (straw), ears or seedpods, and seeds, for those that affect successive operations, particularly storage and preservation (Gutema & Tadesse, 2022)..

2.5 Post-Harvest Physiology of Papaya

After harvesting, the quality of papaya fruit can be significantly diminished by multiple factors. Like other fruits, the shelf life of papaya may be influenced by internal factors such as respiration, biological structure, ethylene generation and responsiveness, moisture loss, compositional alterations, maturation processes, and physiological degradation (Singh *et al*., 2021).

2.5.1 Respiration

A significant metabolic process that occurs in harvested produce or any living plant material is respiration. This process involves the breakdown of stored organic substances, such as carbohydrates, proteins, fats, and other organic materials, into simpler end products, accompanied by the release of energy. During respiration, there is a depletion of the stored food reserves in the commodity. This accelerates aging because the energy-providing reserves are depleted (Daley *et al*., 2023).

2.5.2 Ethylene production and sensitivity

Physiologically, papaya is a climacteric fruit that follows typical patterns of respiration and ethylene production as it ripens. When ripening begins, respiration increases to a peak (the climacteric peak) and then gradually decreases. This rise in respiration is preceded by a similar pattern of heightened ethylene production (Kahramanoglu, 2023).

2.5.3 Transpiration

Transpiration refers to the process where water evaporates from plant tissues. This phenomenon significantly contributes to the deterioration of produce, leading to serious impacts. Initially, the loss of water results in a decrease in marketable weight, and subsequently, it negatively affects the appearance, causing wilting and shriveling. Additionally, the textural quality diminishes due to increased softening and a decline in crispness and juiciness, followed by a decrease in nutritional value (Zeboon & Baqir, 2022).

2.6 Post-harvest biochemistry of papaya

2.6.1 Enzyme activity

During the ripening of papaya fruit, there is a strong correlation between indicators of ripening, respiration, ethylene production, skin color, and the activity of enzymes that break down the cell wall. The enzymes identified include polygalacturonase (PG), pectin methylesterase (PME), xylanase, and cellulase. There is a connection between PG and xylanase and the softening of the fruit (Kebede, 2020). The maximum activity of xylanase and PG is observed when the fruit exhibits 40 to 60% yellowing of the skin (N. Wang *et al*., 2025).

2.6.2 Carbohydrates

The most significant quantitative change that occurs during ripening is typically the breakdown of carbohydrate polymers, particularly the almost complete transformation of starch into sugars. This change affects both the flavor and texture of the produce. The rise in sugar content makes the fruit considerably sweeter and, consequently, more appealing (Phillips *et al*., 2021). Carbohydrates are the predominant biochemical components found in fruits, constituting approximately 50 to 80% of their overall dry weight. They serve as a form of stored energy and contribute significantly to the structural framework of the cells (Vicente *et al*., 2022).

2.6.3 Organic acids

Non-volatile organic acids constitute the majority (80 to 90%) of the overall acidity in fruits. Citric and malic acids are the main acids, although tartaric, malonic, fumaric, and succinic acids may also be present (Banothu, 2020).

2.6.4 Pigments

The gradual softening of the tissue, along with alterations in the skin or flesh color and the generation of various aroma compounds, are among the most noticeable changes that occur during the ripening process of climacteric fruit (Priyadarsini, 2020).

2.6.5 Volatiles

Numerous unstable aromatic substances have been discovered in papaya fruit (Banothu, 2020) According to (Kebede, 2020) There are approximately 106 unstable compounds present in papaya fruit. The quantity of each compound differs depending on the variety and growing region, with linalool being a primary component.

2.7 Post-harvest microbiology of papaya

The spoilage of horticultural products due to microorganisms between the time of harvest and consumption can occur swiftly and intensely, especially in tropical regions where high temperatures and elevated relative humidity facilitate rapid microbial proliferation. Additionally, ethylene emitted by decaying produce can lead to premature ripening and aging of nearby produce within the same storage and transportation settings, while healthy produce can become contaminated by organisms from decaying items. Fruits may become infected through direct penetration by certain fungi through an intact cuticle, or through injuries and natural openings on their surface (Green Fields & Pradesh, 2024).

2.8 Post-Harvest Handling of Papaya

The quality of harvested fruits and vegetables relies on their growth conditions, along with the physiological and biochemical transformations they experience after being picked. For ensuring optimal shelf life and maintaining quality after harvest, it is crucial to harvest fruits at the right stage (Kebede, 2020). During routine handling processes like loading, unloading, transportation by air or truck, warehouse storage, and retail display, fruits and vegetables are frequently subjected to unsuitable temperatures. This is often due to challenges in temperature management, unavailability of refrigerated facilities, or insufficient knowledge about the specific requirements and characteristics of the produce (Kebede, 2020).

2.8.1 Packaging

Packaging fresh produce is necessary not only to ensure ease of handling, but also to maintain the quality of the product during distribution and, in some instances, to enhance its value during marketing. Packaging solutions are tailored to the specific product, yet they can aid in preserving quality by shielding against rough handling, preventing moisture loss, and

limiting metabolic activity. Packaging offers defense against physical harm throughout storage, transportation, and marketing (Kebede, 2020).

2.8.2 Storage temperature and relative humidity management

Papaya fruits kept in typical tropical temperatures (30°C) can be stored for a maximum of seven days (Prasad & Paul, 2021). It was also observed that raising the relative humidity of storage and lowering the temperature by utilizing an adiabatic cooling method, where evaporative cooling minimized physiological weight loss in papayas, compared to those stored at room conditions (Tolesa *et al*., 2023).

2.9 Spray drying

Drying is one of the oldest techniques used to preserve foodstuffs. The first patent on the use of spray drying technique dates back to 1872 (Çelik et al., 2021), but it was the urgent need to preserve foods, as well as to reduce its weight and volume, which led to the height of the spray drying technique that occurred during the Second World War (Binesh *et al*., 2023). Spray drying is a common process to obtain dry powders with low moisture content from liquid products as solutions, emulsions or suspensions (Hao *et al*., 2021). The process involves the transformation of feed slurry into a dried particulate form by spraying in a hot drying medium which is generally air (Cabrera-Roque *et al*., 2023).

Several advantages are recognized to this technique such as its low cost, its high reproducibility and its applicability to thermo-labile materials due to the short drying time. Additionally it is easy to operate and to scale-up, and it is very fast, since the particles are produced while they are dried (Zhang *et al*., 2024). Although several factors may influence the quality of spray-dried products (Phing & Saleena, 2022) using this technique, it is possible to obtain a final product with low water activity, ensuring its microbiological stability, reduced weight and volume, facilitating its storage, transportation and commercialization.

2.9.1 Drying Techniques

Drying techniques are essential for converting perishable food materials into stable powders with extended shelf life, improved handling, and ease of transportation. Several methods are

employed depending on the nature of the food product, desired quality, and economic considerations. Common drying techniques include:

2.9.1.1 Spray Drying

A rapid drying process where liquid or semi-liquid food materials are atomized into fine droplets and dried with hot air, producing powders with good solubility and uniform particle size (Athira *et al*., 2023).

2.9.1.2 Freeze Drying (Lyophilization)

A low-temperature process where food is frozen and then dried under vacuum, preserving heat-sensitive nutrients, aroma, and flavors; ideal for high-value products (Widowati *et al*., 2024).

2.9.1.3 Hot Air Drying

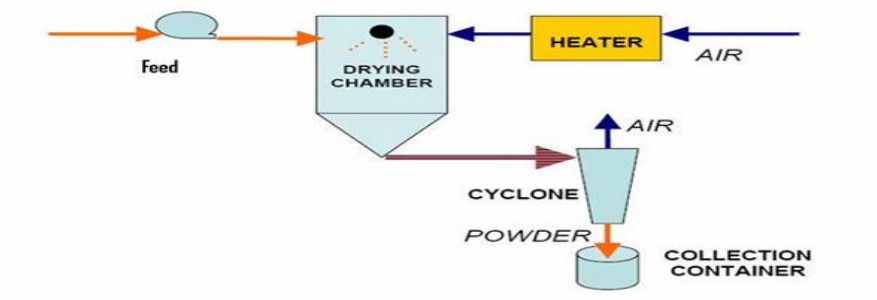
Traditional method involving the exposure of food to hot air in cabinet or tunnel dryers, suitable for bulk drying but may lead to nutrient degradation and color changes (Naik *et al*., 2023).

2.9.1.4 Vacuum Drying

Drying under reduced pressure to lower the boiling point of water, reducing thermal damage and preserving quality (Vega-Gálvez *et al*., 2021).

2.9.1.5 Sun Drying

An economical and simple method utilizing solar energy; however, it is dependent on weather conditions and has higher risks of contamination (Minuye *et al*., 2021).



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Figure 1: Schematic representation of the spray drying process

2.9.2 Principles of the technique

The procedure consists of four key stages, as illustrated in Figure 1. Initially, the liquid sample is transformed into a spray by an atomizing device. These tiny droplets are then exposed to heated air in a drying chamber, leading to the evaporation of moisture and the creation of dry solid particles. Lastly, the solid particles are removed from the airflow and gathered in a collection device (Barbosa, 2015). Each of the process steps will be discussed in detail in subsequent sections.

2.9.2.1 Atomization

The core component of any spray dryer is the atomizer. Despite its small size, it plays a critical role, making the selection of the right atomizer crucial for successful spray drying. This process is the key aspect of the spray dryer, where the liquid, typically delivered by a peristaltic pump, is broken down into a multitude of spray droplets. For this purpose, an atomizer is needed, positioned inside the drying chamber. Greater energy input leads to smaller droplet sizes. Keeping energy input constant while increasing the feed rate results in larger droplet sizes, as well as higher viscosity and surface tension of the initial sample. (Jaskulski & Wawrzyniak, 2024).

Depending on the type of sample and the desired properties of the powder, various atomizers can be selected: centrifugal or rotary atomizers, hydraulic or pressure nozzles, two-fluid or pneumatic nozzles, and ultrasonic nozzles (Binesh *et al*., 2023).

The atomizer needs to serve several key functions which are outlined below:

i. It should disperse the feed material into fine droplets that are evenly distributed within the dryer and thoroughly mixed with the hot gas.

ii. The droplets formed should neither be too large, leading to incomplete drying, nor too small, making product recovery difficult. Small droplets may also overheat and be scorched.

iii. Additionally, the atomizer should function as a metering device, regulating the flow rate of material into the dryer. This can be achieved using: a) air atomization or two-fluid nozzles, b) airless nozzles, c) pressure nozzles, d) rotary or disk nozzles, and e) ultrasonic nozzles.

2.9.2.2 Contact of sprayed particles and hot air

In the drying chamber, while atomization is still occurring, the particles that are sprayed meet hot air, initiating the drying process. The typical shape of vertical drying chambers is cylindrical with a reversed cone at the bottom. They can be either tall-form or short-form configurations, depending on their height to diameter ratios of 5:1 and 2:1, respectively. (Binesh *et al*., 2023). The short-form design is frequently utilized, primarily because it allows for the use of rotary atomizers, whereas in the tall-form design, the use of pressure or two-fluid nozzle atomizers is necessary (Benavides-Morán *et al*., 2021). Their choice should be determined by the required particle size, the temperature that the particles can endure, and the method of distributing the particles (Binesh *et al*., 2023).

2.9.2.3 Evaporation of droplets water

In the contact between the sprayed particles and hot air, the heat transfer is carried out by convection from air to the droplets and the moisture transfer is carried out in the reverse direction due to vapor pressure difference (Manik *et al*., 2023). Evaporation occurs through migration of moisture from inside of the droplet at a constant temperature and constant partial vapor pressure at the surface of the droplet. Moisture diffusion rate from the inner to the surface of the droplet is constant to be able to maintain the saturated conditions at the surface. When the moisture content inside the particle reaches a critical value a dry skin is formed at its surface, so that evaporation become dependent on the diffusion rate of moisture through the dry skin. Its thickness increases and the evaporation rate is reduced. The drying is completed when the temperature of the particle becomes equal to the temperature of the air (Eghbal *et al*., 2022). The heat and mass transfer rate depends on the particle size and the relative rate of air and particles (Gulmez *et al*., 2021).

2.9.2.4 Separation of dried product and humid air

The final step of the spray drying process consists in the separation of dried product from the humid drying air. This separation often occurs outside the drying chamber in suitable devices, such as cyclone separators. It may also occur inside the drying chamber, but scraping tools are required for the collection of the dried product, such as mechanical brushes or vibratory devices (Binesh *et al*., 2023). The separation by cyclone is based on the difference of density

between dry product and humid air. It is produced a rotating vortex by a high speed flow field, which throws the dry particles towards the walls and downwards of the cyclone (Nespi *et al*., 2021).

2.9.2.5 Feed rate

Feed rate is related to the moisture content of the powders, since, if the atomizer is fed too quickly, the sprayed droplets will have a shorter contact time with hot air, so the evaporation of water droplets will be lower, as well as the drying yield, due to the deposit on the dryer walls (Phing & Saleena, 2022). The feed rate influences the moisture content and particle size of the final powder. Studies suggest that lower feed rates may result in higher quality powders with better solubility (Oliveira *et al*., 2022). The feed rate influences the residence time of droplets in the drying chamber and impacts the moisture content of the final product. (Qadri *et al*., 2023) conducted a study on the optimization of feed rates during the spray drying of fruit powders, including papaya. They found that lower feed rates allowed for better moisture removal but could lead to higher energy consumption. Conversely, higher feed rates resulted in increased moisture content in the final product.

2.9.2.6 Inlet air temperature

Different inlet air temperatures have been studied in the spray drying of various fruit juices over the years and this drying parameter affected all properties of the obtained powders. At higher inlet air temperatures an excessive evaporation occurs, which results in lower moisture content of powders. Innumerous authors reported this fact (Ghalegi Ghalenoe *et al*., 2021). An increase of the inlet air temperature can also cause a quick formation of an impermeable dried layer in the droplet surface, which lead to the formation of porous particles, resulting in low bulk densities (Kim *et al*., 2021) .

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Experimental location

The study was conducted at the Agro-processing Faculty Laboratory of the Federal Technical and Vocational Education and Training Institute (FTVETI) and the Food Science Department Laboratory of Addis Ababa Science and Technology University during 2025 and 2026 to optimize spray drying process conditions for the production of instant papaya powder.

The analyses of process yield, total soluble solids (TSS), pH, and sensory evaluation were carried out at the Agro-processing Faculty Laboratory of FTVETI. Moisture content, water activity, bulk density, water holding capacity, oil holding capacity, solubility, and viscosity analyses were conducted at the Food Science Department Laboratory of Addis Ababa Science and Technology University..

3.2 Sample Collection and preparation

Mature papaya fruits with yellow pulp were collected from Melkassa Agricultural Research Center. Harvesting was carried out manually in the early morning by experienced personnel to minimize mechanical damage. The fruits were selected based on uniformity of size, shape, skin color, and absence of physical defects. The selected fruits were allowed to ripen uniformly for 5 days until 75% of the peel color turned yellow. The fruits were washed using tap water containing 2% sodium hypochlorite solution to reduce microbial contamination and remove adhering dirt particles as this percent of sodium hypochlorite solution is enough to reduce microbial load. The washed fruits were surface dried using a soft cloth. The ripening stage of the fruits was further confirmed by measuring total soluble solids (TSS) using a portable digital refractometer and pH using a portable pH meter. The papaya fruits were manually peeled using a stainless-steel knife, cut longitudinally, and the seeds were removed. The pulp was sliced into pieces 5 mm thick as measured using a digital caliper.

The sliced papaya samples were pretreated by soaking in an ascorbic acid solution prepared by dissolving 34 g of ascorbic acid in 1 L of water to minimize enzymatic browning and discoloration during processing following the method described by(Y. Wang *et al*., 2026).

Ascorbic acid pretreatment helps retard oxidation reactions and preserve the color quality of fruit tissues during drying, as reported by (Y. Wang *et al*., 2026)). Papaya slices were processed using a domestic juicer to obtain papaya pulp. The extracted juice was filtered through muslin cloth to remove suspended solids and prevent blockage of the spray dryer atomizer. Seven kilograms of papaya pulp were mixed with 1.05 kg maltodextrin (15% w/w pulp basis). 2 liters of water were added to obtain suitable feed consistency for spray drying. The mixture was homogenized using a magnetic stirrer for 20 min.

3.3 Processing Flow Chart for Spray-Dried Papaya Powder



Figure 2: Processing flow chart for spray-dried papaya powder production ***(Pujapanda et al*., 2025)**

3.4 Spray Dryer Setup and Operating Conditions

A laboratory-scale BÜCHI Mini Spray Dryer B-290 equipped with a pneumatic two-fluid nozzle having a diameter of 0.7 mm was used for the experiment. The drying chamber had dimensions of approximately 0.65 m diameter and 1.1 m height. Compressed air was supplied at a pressure of 5–8 bars. The prepared feed solution containing papaya pulp, maltodextrin, and water was spray dried under different operating conditions. The feed solution was pumped into the spray dryer at feed flow rates of 6, 8, and 10 mL/min. The inlet drying temperatures used were 150°C, 165°C, and 180°C, while fan speed levels were maintained at 60%, 70%, and 80%, following procedures reported in previous spray-drying studies(do Nascimento Remigio *et al*., 2024).

Prior to each drying experiment, the spray dryer was calibrated by running distilled water through the system to ensure proper functioning and stable operating conditions. The spray-dried papaya powder samples were collected, cooled, packed in non-transparent glass containers, and stored at 4°C until analysis (Singla & Sit, 2024).

3.5 Experimental Design and Optimization

Response Surface Methodology (RSM) using a three-factor, three-level Box–Behnken Design (BBD) was employed to optimize the spray drying process parameters(Uoorakkottil *et al*., 2025). Design Expert software version 13.0.5.0 (Stat-Ease Inc., Minneapolis, USA) was used for generating the experimental design and statistical analysis. The independent variables selected for the study were inlet drying temperature, feed rate, and fan speed. The levels of these variables were selected based on preliminary studies and related literature on spray drying of fruit juices (Phing & Saleena, 2022). The dependent response variables included process yield, moisture content, water activity, bulk density, and water holding capacity, oil holding capacity, solubility, total soluble solids, viscosity, pH, and sensory attributes.

Table 2: Criteria employed to optimize processing variables

Process parameters / Responses	Optimization Goal	Lower limit	Upper limit
Inlet drying temperature (°C)	In Range	150	180
Feed rate (ml/min)	In Range	6	10
Fan speed (%)	In Range	60	80
Process yield (%)	maximize	65.2	82
Moisture content (%)	minimize	2.8	5.3
Water activity	minimize	0.31	0.48
Bulk density (g/ml)	Minimize to moderate (for better instant properties and lighter powder)	0.28	0.34
Water holding capacity(g/g)	Optimize	1.8	2.4
Oil holding capacity(g/g)	Optimize	1.1	1.5
Solubility(%)	maximize	83.4	89.2
Total soluble solids (%)	Maximize	8	9.1
Viscosity((cP)	Optimize	32	45
pH	Maintain optimum acidic range	4.1	4.4
Color (9-point hedonic scale)	Maximize color retention	5.7	7.1
Flavor	Maximize	5.7	7.1
Aroma	Maximize	6	7.5
Taste	Maximize	5.4	7.2
Overall acceptability	Maximize	5.7	7.3

Source: Adapted from(Lamidi *et al*., 2022)

As shown in Table 3.1, the objective of the optimization was to determine the optimum combination of the three process parameters that would produce desirable quality

characteristics of spray-dried instant papaya powder. Based on preliminary studies, the inlet drying temperature ranged from 150°C to 180°C, the feed rate ranged from 6 to 10 mL/min, and the fan speed ranged from 60% to 80%(Phing & Saleena, 2022).

3.6 Experimental Plan Runs and Treatment Combinations

The Box–Behnken experimental design generated a total of 15 experimental runs for the optimization study.

The inlet drying temperature levels were 150°C, 165°C, and 180°C. Feed rate levels were 6, 8, and 10 mL/min, while fan speed levels were 60%, 70%, and 80%.This temperature range was selected to achieve efficient drying while minimizing the thermal degradation of heat-sensitive bioactive compounds present in papaya pulp. Lower temperatures may result in incomplete drying and the formation of sticky powder, whereas higher temperatures may cause excessive browning, vitamin loss, and degradation of antioxidant compounds. (Anisuzzaman *et al*., 2022) .

Feed rate levels of 6, 8, and 10 mL/min were selected to regulate the amount of feed solution introduced into the drying chamber and to ensure adequate contact time between the feed droplets and the drying air. Lower feed rates may result in excessive drying and reduced production efficiency, whereas higher feed rates may lead to incomplete drying, higher moisture content, and powder agglomeration or stickiness(Chan *et al*., 2024).

Fan speed levels of 60%, 70%, and 80% were selected for the experiment. The aspiration rate, which is associated with fan speed, plays an important role in controlling the airflow through the drying chamber and consequently affects the drying rate, particle residence time, and moisture removal efficiency. Maintaining an appropriate fan speed range ensured effective moisture removal while minimizing thermal degradation and powder losses during spray drying (Jagdale,2025).

Table 3: Experimental plan runs and Treatment Combination

Run	Inlet Temperature (°C)	Feed (ml/min)	Fan Speed (%)
1	150	6	70
2	180	6	70
3	150	10	70
4	180	10	70
5	150	8	60
6	180	8	60
7	150	8	80
8	180	8	80
9	165	6	60
10	165	10	60
11	165	6	80
12	165	10	80
13	165	8	70
14	165	8	70
15	165	8	70

Optimization of the three main process variables was performed using Response Surface Methodology (RSM) with Design Expert Software version 13.0.5.0. A three-factor, three-level Box–Behnken Design (BBD) was employed for the optimization study. Accordingly, a total of 15 experimental runs were generated and conducted to evaluate the effects of inlet drying temperature, feed rate, and fan speed on the quality attributes of spray-dried instant papaya powder (Apichatwatana *et al*., 2025).

3.7 Analysis of Spray-Dried Papaya Powder

3.7.1 Physical Quality Parameters

3.7.1.1 Process yield

The process yield of spray-dried papaya powder was determined according to the method described by (Farías-Cervantes et al., 2020). Process yield was calculated based on the ratio

of the weight of powder obtained after spray drying to the total dry matter content of the feed solution. The process yield was calculated using Equation (1).

$$\text{Process Yield (\%)} = \frac{\text{Weight of spray-dried powder (g)}}{\text{Dry weight of papaya juice (g)} + \text{Weight of maltodextrin (g)}} * 100$$

3.7.1.2 Moisture content

The moisture content of the papaya powder was determined using AOAC 935.29 standard method (L. S. Chang et al., 2020). 2 g of powder sample were weighed into pre-dried and pre-weighed aluminum dishes and dried in a hot air oven at 105°C for 24 h. After drying, the samples were cooled in a desiccator and weighed until constant weight was obtained. Moisture content was calculated using Equation (2) and expressed as percentage wet basis.

$$\%\text{Moisture content (w/w)} = \frac{\text{Weight of wet sample (g)} - \text{Weight of dry sample (g)}}{\text{Weight of dried sample (g)}} \times 100\%$$

3.7.1.3 Water Activity (Aw)

Water activity (aw) of the spray-dried papaya powder was determined using a Lab Master water activity meter (Novasina, Switzerland) .The instrument was switched on 1 h before analysis to allow stabilization. 2 g of powder sample were placed in the sample holder and the readings were recorded at room temperature(L. S. Chang *et al*., 2020).

3.7.1.4 Bulk density

Bulk density was determined according to the method reported by (Santana *et al*., 2021). 5 g of papaya powder were transferred into a 50 mL graduated cylinder. The cylinder was gently tapped manually 20 times on a laboratory bench until a constant volume was obtained. Bulk density was calculated using Equation (3) and expressed as g/mL.

$$\text{Bulk density (BD)} = \frac{\text{Weight of powder (g)}}{\text{Volume of powder (mL)}} \quad (4)$$

3.8 Functional Properties of Spray-Dried Papaya Powder

3.8.1 Water Holding Capacity and Oil Holding Capacity

Water holding capacity (WHC) and oil holding capacity (OHC) were determined as important functional properties of spray-dried papaya powder. These properties indicate the ability of the powder to retain water and oil in food formulations. High WHC contributes to improved texture, viscosity, and reduction of syneresis in food products, whereas OHC is influenced by the chemical and physical structure of the powder components (G. Jiang *et al*., 2024).

3.8.2 Solubility

The solubility of the spray-dried papaya powder was determined according to the method described by (Amunugoda *et al*., 2020). 400 mL of distilled water were heated to 70°C and about 0.5 g of powder sample were added to the hot water and stirred continuously. The time required for complete dissolution was recorded using a stopwatch. Solubility was calculated using Equation (4) and expressed as seconds per gram (s/g)

Solubility=Time required to dissolve the dry powder (s) / Weight of powder (g)

3.9 Analysis of reconstituted powder

3.9.1 Chemical Quality Parameters

3.9.1.1 Determination of Total Soluble Solids (TSS)

The spray-dried papaya powder was reconstituted using distilled water to obtain a total soluble solids content similar to that of the original papaya puree before spray drying, following the method of (Lourenço *et al*., 2020).

2 g of papaya powder were dissolved in 20 mL of warm distilled water and stirred until a uniform light orange-yellow solution was formed. Additional powder was gradually added until the total soluble solids reached approximately 9.8 ± 0.1 °Brix. The reconstituted samples were then used for viscosity and pH analyses

3.9.1.2 Viscosity

Viscosity was measured using a Brookfield viscometer (DV-II+ Pro, Brookfield, USA) equipped with Rheocalc software according to the method described by L. S. Chang *et al*. (2020). The Ultra-Low Adapter (ULA) spindle was used and the instrument was auto-zeroed before analysis. Approximately 15 mL of reconstituted sample were transferred into the sample chamber and the viscosity was measured at room temperature at a rotational speed of 200 rpm(L. S. Chang *et al*., 2020).

3.9.1.3 pH value

The pH of the reconstituted papaya powder samples was determined using a digital pH meter (Jenway, UK). 2 g of powder sample were dissolved in 25 mL of distilled water. The pH meter was calibrated using standard buffer solutions of pH 4.0 and 7.0 before measurement. The electrode was immersed in the sample solution and the pH value was recorded at room temperature(Perera *et al*., 2025).

3.10 Sensory evaluation

Sensory evaluation of the optimized spray-dried instant papaya powder was conducted to assess consumer acceptability and the effect of spray-drying conditions on the organoleptic properties of the product. The evaluation was carried out in the laboratories of the Agro-Food Processing Technology Faculty, Federal Technical and Vocational Education and Training Institute, using reconstituted powder samples prepared under standardized conditions and evaluated under fluorescent lighting conditions on the organoleptic attributes of the product namely color, flavor, aroma, taste and overall acceptability (Perera *et al*., 2025).

3.10.1 Panelist Selection

A total of 15 semi-trained panelists participated in the sensory evaluation. The panelists consisted of staff members of the Federal Technical and Vocational Education and Training Institute and BSc and MSc students from the Agro-Food Processing Technology Faculty. The panel comprised seven males and eight females, aged between 24 and 36 years, who were non-smokers and familiar with fruit-based products. Participation was based on willingness and availability.

3.10.1.1 Panelist Orientation

Prior to evaluation, panelists were briefed on the objective of the study and the sensory evaluation procedure. They were instructed on how to use the 7-point hedonic scale and were trained to evaluate samples independently. Discussion among panelists was not allowed to avoid bias. Clean water was provided for rinsing the mouth between samples to minimize carry-over effects.

3.10.1.2 Sample Preparation and Presentation

Spray-dried papaya powder samples were reconstituted under standardized conditions by dissolving the powder using warm distilled water prior to sensory evaluation. Each sample was placed in identical cups and coded with random three-digit numbers to ensure blinding. Samples were presented in randomized order, and equal quantities were provided to each panelist under fluorescent lighting conditions.

3.10.1.3 Sensory Evaluation Procedure

Each panelist evaluated the samples individually based on color, flavor, aroma, taste and overall acceptability. A 7-point hedonic scale was used, where 7 indicated “Like extremely” and 1 indicated “dislike extremely.” Panelists were instructed to rinse their mouth with water between samples to prevent carry-over effects.

3.10.1.4 7-Point Hedonic Scale

The sensory scoring scale used was as follows:7=,7=Like extremely,6=Like very much, Slightly,5=Like moderetly,4=Neither Like Nor Dislike,3=Dislike Moderately,2=Dislike Very Much and 1 = Dislike extremely

The sensory scores obtained from all panelists were averaged to determine the mean score for each sensory attribute. The experimental design and statistical analysis were performed using Design-Expert software based on Response Surface Methodology (RSM) with a Box–Behnken Design (BBD). Mean values and standard deviations were calculated for each attribute, and the data were further analyzed to determine the overall acceptability of the optimized spray-dried instant papaya powder.

3.11 Statistical analysis

The experimental data were analyzed using Design-Expert Software version 13.0.5.0 (Stat-Ease Inc., Minneapolis, USA). + (RSM) based on a Box–Behnken Design was employed to evaluate the effects of inlet temperature, feed flow rate, and fan speed on the physicochemical and sensory properties of spray-dried instant papaya powder. Regression analysis and analysis of variance (ANOVA) were performed to develop predictive models, assess the significance of process variables and their interactions, and identify the optimum spray-drying conditions.

The adequacy and significance of the fitted models were evaluated at a 95% confidence level ($p < 0.05$). Response surface and contour plots were generated to illustrate the relationships between the independent variables and the measured responses. Numerical optimization was used to determine the processing conditions that yielded the most desirable quality attributes of the instant papaya powder. Experimental results were expressed as mean ± standard deviation (SD), and differences were considered statistically significant at $p<0.05$.

CHAPTER FOUR

4 RESULT AND DISCUSSION

4.1 The effect of physicochemical properties of optimized spray-dried instant papaya powder

All measured parameters (Process yield, moisture content , water activity, bulk density, water holding capacity, oil holding capacity, solubility, total soluble solid, viscosity and Ph) revealed marked variations between the treatments ($p < 0.05$) indicating that different formulations had great effects on powder quality.

Summery Table. Analysis of variance (ANOVA) for the 15 experimental runs of physicochemical properties of optimized spray-dried instant papaya powder

Sources	Physicochemical parameters									
	Yield	MC	WA	BD	WHC	OHC	Sol	TSS	Visc	pH
Model	0.0001	0.0001	0.0002	0.0027	0.0015		0.0412	0.0705	0.0383	0.0153
Linear mixture	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A*B	0.8752	0.5623	0.5965	0.3907	0.0932			0.0842	0.0425	
A*C	0.2435	0.5623	1.0000	0.1191	0.0016			0.0842	0.1974	
B*C	0.5379	0.2699	1.0000	1.0000	1.0000			0.3053	0.3447	
A^2	0,0184	0.0004	0.0204	0.8863	0.0076					
B^2	0.0219	0.0030	0.0068	0.1589	0.7537					
C^2	0.0096	0.0087	0.0115	0.4859	0.0680					
R2 (adjusted	0.9845	0.9905	0.9714	0.9036	0.9333		0.3805	0.3215	0.5603	0.4869
Lack of fit	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where NS =not significant

Analysis of variance outputs of physicochemical properties of spray-dried instant papaya powder are summarized in Appendix table 1. P-values for quadratic models, linear models and interaction among process components and R squared values were indicated. ANOVA p-values of all the physicochemical properties indicate that quadratic models, linear models and interaction among the process components are significantly ($p < 0.05$) different. Coefficient of determination (R2 values) for physicochemical properties indicated that models can sufficiently predict the responses.

4.1.1 Process yield

The process yield increased significantly from 65.1 ± 0.1% to 81.93 ± 0.12%. The ANOVA results indicated that the quadratic model (Appendix table 2) was highly significant ($p < 0.0001$), demonstrating that the selected spray drying processing variables significantly influenced the response variable. Among the linear terms, inlet temperature (A) had the most significant effect on the response followed by feed rate (B) and fan speed.

This result indicates that inlet temperature was the dominant processing parameter affecting the quality attribute of the powder. In spray drying, inlet temperature strongly influences the heat and mass transfer process, which directly affects moisture evaporation, particle formation, drying efficiency, and powder quality characteristics. Higher inlet temperatures generally increase drying efficiency and accelerate water removal, resulting in rapid crust formation and improved powder characteristics. The highest process yield was obtained at 180°C inlet temperature, 10 mL/min feed rate, and 70% fan speed, whereas the lowest process yield was recorded at 165°C inlet temperature, 10 mL/min feed rate, and 80% fan speed. The increase in process yield with increasing inlet temperature could be attributed to improved heat and mass transfer efficiency during spray drying, resulting in rapid moisture evaporation and reduced powder deposition on the chamber wall. This is in agreement with the result reported by(Salgado-Aristizabal *et al*., 2023).

Feed rate showed a highly significant effect on the response ($p < 0.001$) because it influences droplet residence time and heat transfer efficiency inside the drying chamber. Lower feed rates enhanced moisture evaporation and particle formation due to longer drying time, resulting in improved process yield and powder recovery.

In contrast, increasing feed rate reduced drying efficiency, promoted powder stickiness, and increased process loss due to insufficient atomization and incomplete drying. This is in agreement with the result reported by (Calliari *et al*., 2024), who found that lower feed flow rates improved powder production efficiency.

Fan speed also significantly influenced the response ($p < 0.01$). This could be attributed to its role in controlling airflow dynamics, heat transfer efficiency, and particle separation within the spray dryer. Increased fan speed enhances hot air circulation and improves moisture

removal, thereby affecting powder formation and drying performance. Comparable findings were reported in spray drying studies of fruit powders, where airflow parameters significantly influenced powder recovery and physical quality characteristics(Phing & Saleena, 2022).

The interaction terms AB, AC, and BC were not significant ($p > 0.05$), indicating that the combined interaction effects between inlet temperature, feed rate, and fan speed did not substantially influence the response.

The quadratic terms A^2, B^2, and C^2 were significant ($p < 0.05$), indicating the presence of curvature effects in the model. This suggests that the response did not change linearly across the studied ranges of inlet temperature, feed rate, and fan speed, and that optimum processing conditions existed within the experimental region. Significant quadratic effects are common in spray drying optimization because both excessively low and excessively high processing conditions can negatively affect powder quality. Therefore, moderate levels of the processing variables are usually required to obtain optimum powder characteristics (Aryaee *et al*., 2023).

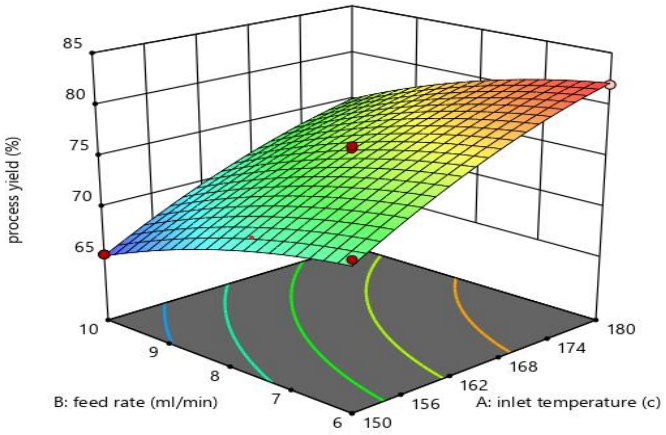
Regression Equation for Process Yield

The regression equation for process yield in terms of coded factors is given as:

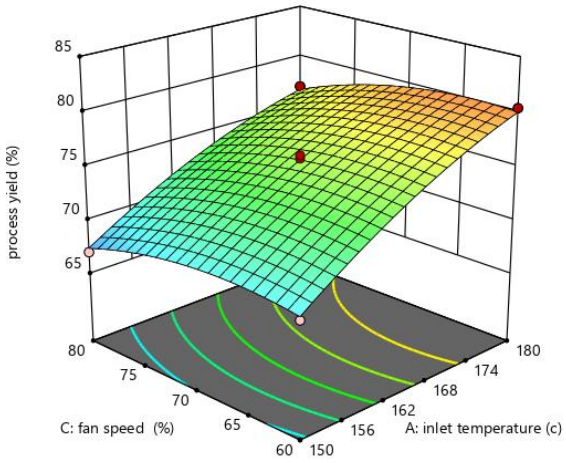
$$Y= 75.67 +5.05A-3.50B-1.27C-0.0500AB-0.4000AC+0.2000BC-1.08A^2-1.03B^2-1.28C^2$$

Where: Y = Process yield (%), A = Inlet temperature, B = Feed rate and C = Fan speed

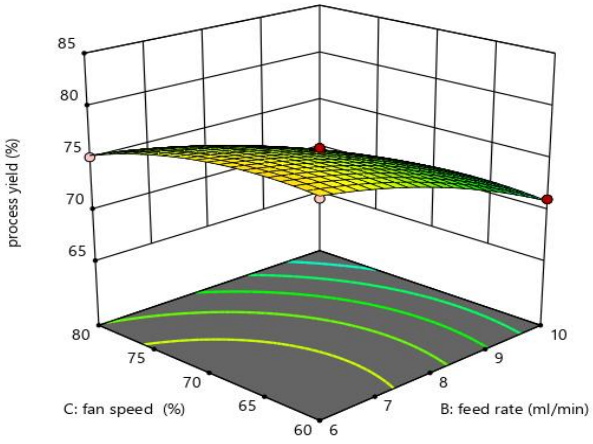
The positive coefficients of inlet temperature indicate that increasing these variables improved process yield, whereas the negative coefficient of feed rate and fan speed showed that higher feed rates and fan speed reduced powder recovery. The negative quadratic terms indicated that excessive levels of the processing variables could decrease the process yield after reaching an optimum point.


process yield (%)
85
80
75
70
65
10
9
8
7
6
B: feed rate (ml/min)
150
156
162
168
174
180
A: inlet temperature (c)

(a)


process yield (%)
85
80
75
70
65
80
75
70
65
60
C: fan speed (%)
150
156
162
168
174
180
A: inlet temperature (c)

(b)


process yield (%)
85
80
75
70
65
80
75
70
65
60
C: fan speed (%)
6
7
8
9
10
B: feed rate (ml/min)

(c)

Figure 3: Three-dimensional surface plots showed the interaction effects of process yield

4.1.2 Moisture Content

The moisture content was decreased from 5.27% ±0.01 % dry bases to 2.77%±0.06 % dry base with increasing inlet drying temperature from 165^{o}c to 180^{o}c. The ANOVA results indicated that the quadratic model (Appendix table 3) was highly significant ($p < 0.0001$), confirming that the spray drying conditions significantly influenced the response of the spray-dried fruit powder. Among the processing variables, inlet temperature showed the highly significant effect ($p < 0.001$), indicating that it was the dominant factor affecting the response.

A highly significant reduction in the moisture content of the powder was observed by up to 47.44% when inlet drying temperature increased. This is due to the fact that at higher inlet drying temperature, there is a larger temperature gradient between the fine droplets feed and the hot drying air, ensuring in greater rate of heat transfer to particle and provide better driving force for moisture evaporation . The significant influence of inlet temperature is mainly associated with its direct effect on heat and mass transfer during drying. Higher inlet temperatures generally accelerate moisture evaporation, improve drying efficiency, and influence powder characteristics such as moisture content, solubility, color, and yield. The result of this study is in agreement with the findings of (M. Nguyen, 2022).

Feed rate also significantly affected the response .The significant contribution of feed rate indicates that the amount of feed entering the drying chamber influenced the drying behavior and final powder quality. Increasing feed rate may reduce the residence time of droplets inside the drying chamber, resulting in incomplete moisture evaporation and higher powder stickiness. Lower feed rates generally improve drying efficiency and powder recovery because the droplets receive sufficient heat exposure for proper drying. Similar observations were reported for spray-dried apple and other fruit powders, where feed flow rate significantly affected moisture content, powder yield, and flow properties(Phing & Saleena, 2022).

In contrast, fan speed) did not significantly affect the response since its p-value was greater than 0.05.

The interaction effects were not significant ($p > 0.05$). This indicates that the combined effects of these processing variables did not substantially influence the response.

The quadratic terms A^2, B^2, and C^2 were all highly significant ($p < 0.01$), indicating the presence of curvature in the response surface. The significant quadratic effect of inlet temperature (A^2) showed that the response did not change linearly across the temperature range, implying that an optimum inlet temperature existed for achieving desirable powder quality. Likewise, the significant quadratic effects of feed rate (B^2) and fan speed (C^2) indicated that extremely low or high values of these variables could negatively affect the response, while intermediate levels produced better results. The significance of the quadratic terms further confirmed the suitability of response surface methodology for optimization of spray drying conditions of instant papaya powder (Salgado-Aristizabal *et al*., 2023).

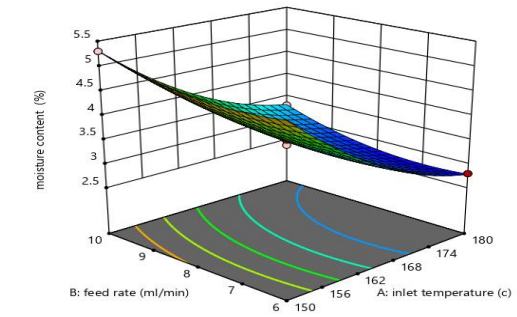
Regression Equation for Moisture Content

The regression equation for moisture content in terms of coded factors is given as:

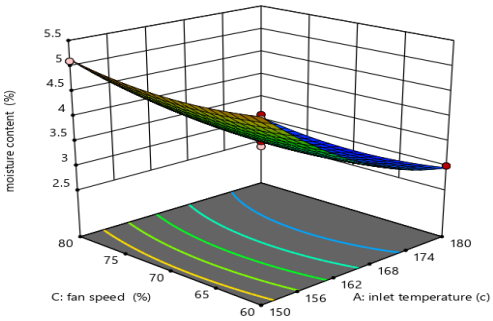
$$Y = 3.5-1.02A+0.2375B+0.0625\ \ C+0.0250AB-0.0250AC+0.0500BC+0.3500\ A^2+0.2250B^2+0.1750\ C^2$$

Where: Y = Moisture content (%), A = Inlet temperature, B = Feed rate and C = Fan speed

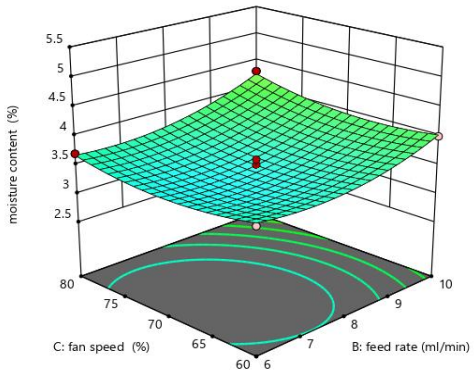
The negative coefficient of inlet temperature indicated that increasing inlet temperature reduced moisture content due to enhanced moisture evaporation during spray drying. In contrast, the positive coefficient of feed rate showed that increasing feed rate increased moisture content because of insufficient drying time. The positive quadratic coefficients indicated curvature effects of the processing variables on moisture content.



(a)



(b)



(c)

Figure 4: Three-dimensional surface plots showed the interaction effects of moisture content

4.1.3 Water activity

The water activity was decreased from 0.48±0.00 to 0.31±0.01 with increasing inlet drying temperature from 165^{o}c to 180^{o}c. The ANOVA results showed that the quadratic model

(Appendix table 4) was highly significant ($p < 0.0001$), indicating that the selected spray drying processing conditions significantly influenced the response of instant papaya powder. A highly significant reduction in water activity was observed by up to 35.42%% when inlet drying temperature increased. This is because the higher inlet drying temperature accelerates moisture evaporation, reducing water activity via greater heat transfer and driving force for drying. The results were consistent with the findings carried out by (M. Nguyen, 2022).

Feed rate significantly affected the response ($p < 0.05$), at higher feed rates, droplets may not receive sufficient thermal energy for complete drying, resulting in higher residual moisture and reduced powder quality. Conversely, lower feed rates improve drying efficiency by increasing residence time and heat exposure of the droplets. Lower feed rate allows longer droplet-air contact, enhancing water removal and lowering water activity (Fathi *et al*., 2022).

Fan speed did not significantly influence the response since the p-value was ($p > 0.05$). This indicates that variations in fan speed within the studied range had relatively little effect on the response compared to inlet temperature and feed rate. The interaction effects were all non-significant ($p > 0.05$). This implies that the combined influence of these variables did not substantially affect the response, and the response was primarily controlled by the individual effects of the processing variables rather than their interactions.

The quadratic terms were all significant ($p < 0.05$), indicating the existence of curvature in the response surface, suggesting that the response varied non-linearly with the processing variables and that optimum spray drying conditions existed within the experimental range for achieving desirable powder quality (Adeyi *et al*., 2022).

Regression Equation for Water Activity

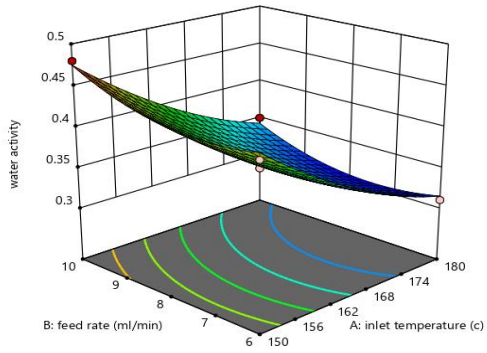
The regression equation for water activity in terms of coded factors is given as:

$$Y=0.35670.0638A+0.0162B+0.0050C0.0025AB+0.0000AC+0.0000BC+0.0154A^2+0.0204B^2+0.0179C^2$$

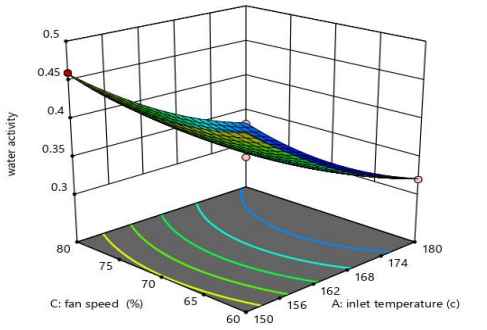
Where: Y = Water activity, A = Inlet temperature, B = Feed rate and C = Fan speed

The negative coefficient of inlet temperature indicated that increasing inlet temperature reduced water activity due to enhanced moisture removal during spray drying. The positive coefficients of feed rate and fan speed indicated that increasing these variables increased

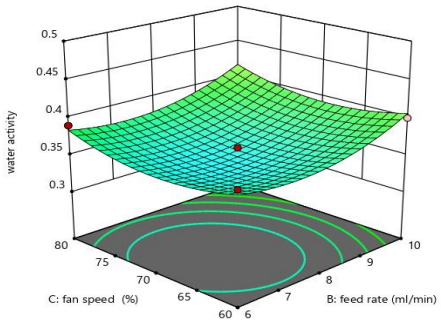
water activity. The positive quadratic coefficients indicated curvature effects of the processing variables on water activity.



(a)



(b)



(c)

Figure 5: Three-dimensional surface plots showed the interaction effects of water activity

4.1.4 Bulk density

The bulk density decreased from 0.34 ± 0.01 g/mL to 0.28 ± 0.01 g/mL as the fluid feed rate was increased from 8ml/min to 10ml/min. The analysis of variance (ANOVA) confirmed that the developed linear model was highly significant ($p < 0.0001$), proving that these independent variables are robust predictors of the physical characteristics of the final powder.

Feed rate showed a highly significant effect on the response ($p < 0.001$). This indicates that the feed flow rate considerably influenced drying efficiency and powder characteristics. At higher feed rates, the droplets may not receive sufficient thermal energy and residence time for complete drying, resulting in increased residual moisture and poorer powder quality. Lower feed rates generally improve drying performance due to better heat transfer and more effective moisture removal. Similar observations were reported in studies of spray-dried tropical fruit powders, where feed rate significantly affected powder yield, moisture content, and functional properties (Nwosu-Obieogu *et al*., 2023).

The resulting powder consists of larger, hollow, and highly porous microstructures. Because these puffed particles contain internal air voids and pack together loosely with substantial interstitial air space, they occupy a much larger volume per unit mass, directly causing the observed drop in bulk density. This finding aligns with the established literature reported by (Koç & Dirim, 2018).

The high inlet drying temperature such as acts as the primary driver for this rapid heat transfer. The temperature accelerates surface moisture evaporation, which is the exact prerequisite needed for the high feed rate to induce particle bloating. Without a sufficiently high inlet drying temperature, the droplet skin would not lock into place fast enough to trap the internal steam, and the particles would simply shrink into denser beads. Therefore, the maximum reduction in bulk density is achieved because the high heat transfer rate from the inlet drying temperature works synergistically with the increased moisture volume from the higher flow feed rates to promote maximum particle expansion and hollowness. *(Nadali et al*., 2022) A similar finding was reported for spray-dried orange juice powder, where increasing inlet air temperature significantly decreased bulk density due to the formation of larger and more porous particles (Mart\’\inez-Navarrete *et al*., 2022).

Fan speed did not significantly affect the response ($p > 0.05$), suggesting that variations in fan speed within the selected experimental range had minimal influence on the response compared to inlet temperature and feed rate. Since only linear terms were included in the model and no quadratic or interaction terms were present, the response was mainly influenced by the direct linear effects of inlet temperature and feed rate.

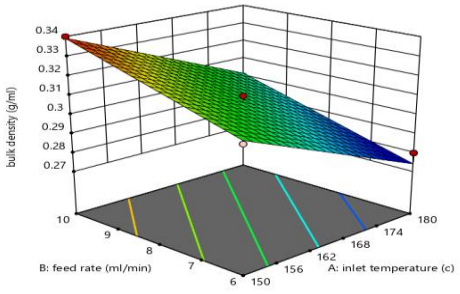
Regression Equation for Bulk Density

The regression equation for bulk density in terms of coded factors is given as:

Y=+0.3067-0.0187A+0.0138 B+0.0025C

Where: BD = Bulk density (g/mL), A = Inlet temperature, B = Feed rate and C = Fan speed

The negative coefficient of inlet temperature indicated that increasing inlet temperature decreased bulk density. On the other hand, the positive coefficients of feed rate and fan speed indicated that increasing these variables slightly increased the bulk density of the powder.



(a)

Figure 6: 3D response surface plot showing effect of inlet temperature and feed rate on the bulk density

4.1.5 Water holding capacity

The water holding capacity (WHC) decreased from 2.39 ± 0.01 g/g to 1.77 ± 0.06 g/g. This result is in agreement with findings were reported by(Ankeli et al., 2025). The ANOVA results indicated that the developed quadratic model (Appendix table 6) was significant ($p \leq 0.05$), showing that the selected spray drying processing variables significantly influenced the response of instant papaya powder.

Among the linear factors, inlet temperature had a highly significant effect on the response with ($p \leq 0.01$). This indicates that inlet temperature was one of the most influential parameters affecting the response. The strong effect of inlet temperature is associated with its direct influence on heat transfer and moisture evaporation during spray drying. Higher inlet temperatures generally enhance drying efficiency and influence powder properties such as moisture content, solubility, yield, and particle characteristics. However, excessive temperatures may also result in degradation of heat-sensitive nutrients and undesirable quality changes (Kucharska-Guzik *et al*., 2025).

Feed rate significantly affected the response ($p \leq 0.05$). This suggests that the rate at which the papaya pulp entered the drying chamber influenced drying performance and powder quality. Increasing feed rate may reduce the residence time of droplets inside the drying chamber, resulting in incomplete drying and higher residual moisture. Lower feed rates generally improve drying efficiency due to more effective heat transfer and sufficient drying time (Baruroh *et al*., 2025).

Fan speed showed a highly significant effect on the response ($p \leq 0.01$), among the linear factors. This indicates that fan speed played a major role in determining the response of the spray-dried papaya powder. The significant effect of fan speed may be related to its influence on airflow pattern, particle residence time, and heat distribution inside the spray dryer. Proper airflow improves moisture removal and powder collection efficiency, thereby affecting powder quality and stability (Z. Jiang *et al*., 2022).

Among the interaction terms, only the interaction between inlet temperature and fan speed (AC) was significant ($p \leq 0.05$). This indicates that the combined effect of inlet temperature and fan speed significantly influenced the response. The result suggests that the influence of inlet temperature on the response depended on the level of fan speed used during spray drying. At certain combinations, improved airflow may enhance heat transfer efficiency and drying performance, while unfavorable combinations may negatively affect powder formation and quality (Qadri *et al*., 2023).

In contrast, the interactions between inlet temperature and feed rate (AB) and between feed rate and fan speed (BC) were not significant ($p > 0.05$), indicating limited combined influence of these factors on the response.

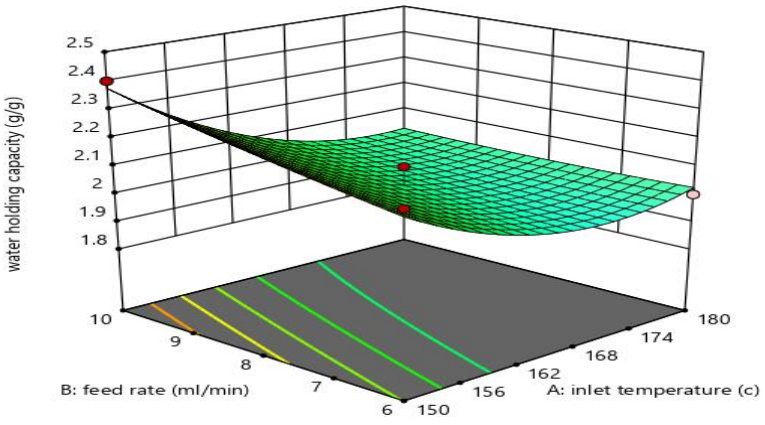
Regarding the quadratic effects, only the quadratic term of inlet temperature (A^2) was significant ($p = 0.0076$). This indicates the presence of curvature in the response surface for inlet temperature, suggesting that the response changed non-linearly with temperature and that an optimum inlet temperature existed within the studied range. Extremely low or high temperatures may negatively affect the response, whereas intermediate temperatures may produce better powder quality. The quadratic terms of feed rate (B^2) and fan speed (C^2) were not significant, implying that these variables affected the response mainly in a linear manner within the experimental range.

Regression Equation for Water Holding Capacity

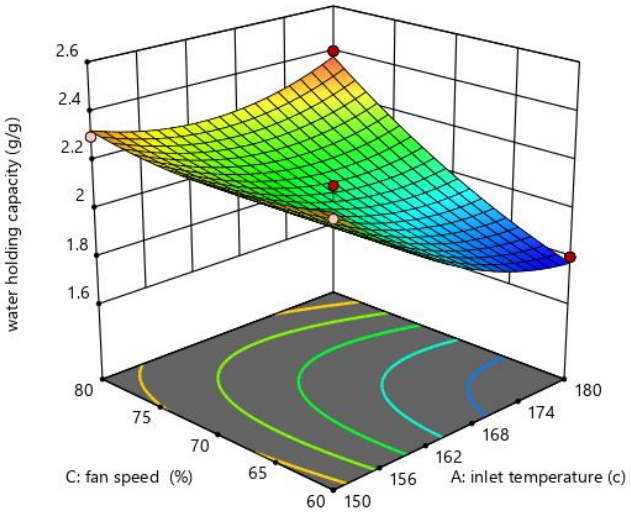
$$Y = +2.03-0.1250A+0.0500B+0.1500C-0.0500AB+0.1500\ AC+0.0000BC+0.1083\ A^2+0.0083B^2+0.0583\ C$$

Where: Y= Water holding capacity (g/g), A = Inlet temperature, B = Feed rate and C = Fan speed

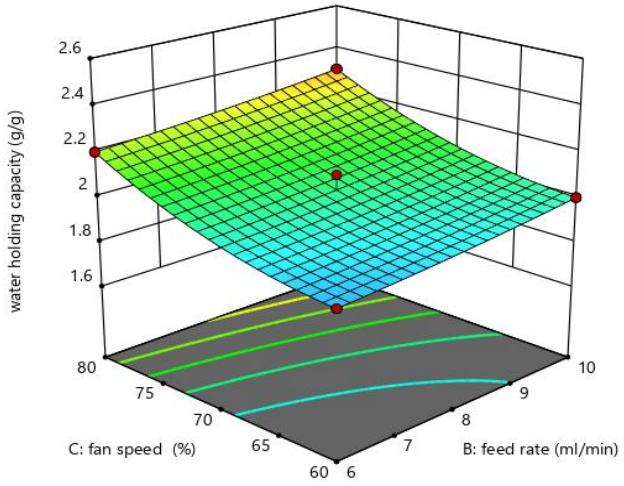
The negative coefficient of inlet temperature indicated that increasing inlet temperature reduced water holding capacity. Conversely, the positive coefficients of feed rate and fan speed indicated that increasing these variables improved the water holding capacity of the powder. The interaction term between inlet temperature and fan speed (AC) positively influenced water holding capacity, while the interaction between inlet temperature and feed rate (AB) showed a slight negative effect.


water holding capacity (g/g)
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
10
9
8
7
6
B: feed rate (ml/min)
150
156
162
168
174
180
A: inlet temperature (c)

(a)


water holding capacity (g/g)
2.6
2.4
2.2
2
1.8
1.6
80
75
70
65
60
C: fan speed (%)
150
156
162
168
174
180
A: inlet temperature (c)

(b)



(c)

Figure 7: Three-dimensional response surface plots showing the interaction effects of water holding capacity

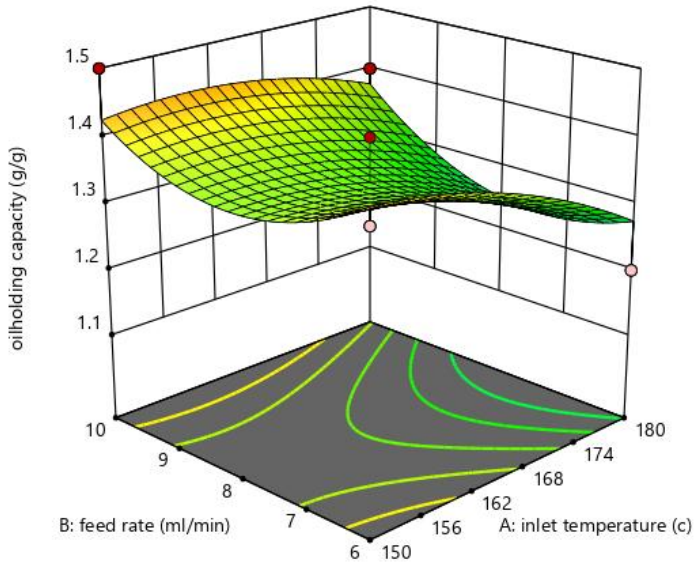
4.1.6 Oil Holding Capacity (OHC)

Oil holding capacity ranged from 1.07 ± 0.06 g/g to 2.00 ± 0.01 g/g. The mean model was suggested for this response because none of the developed regression models (Appendix table 7) were statistically significant ($p > 0.05$), this indicates that the investigated spray drying variables had limited influence on the response within the studied experimental range (D. Q. Nguyen *et al*., 2018).

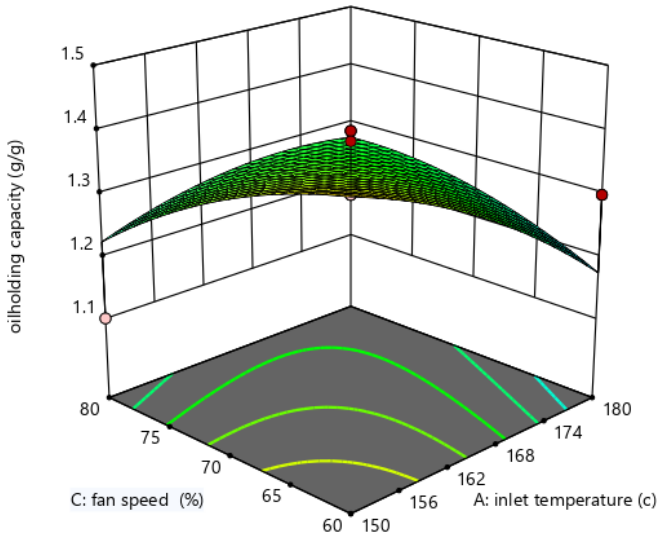
Regression Equation for oil holding capacity

OHC=1.33, Where: OHC= oil holding capacity (g/g), 1.33 is the overall mean oil holding capacity obtained from the experimental data.

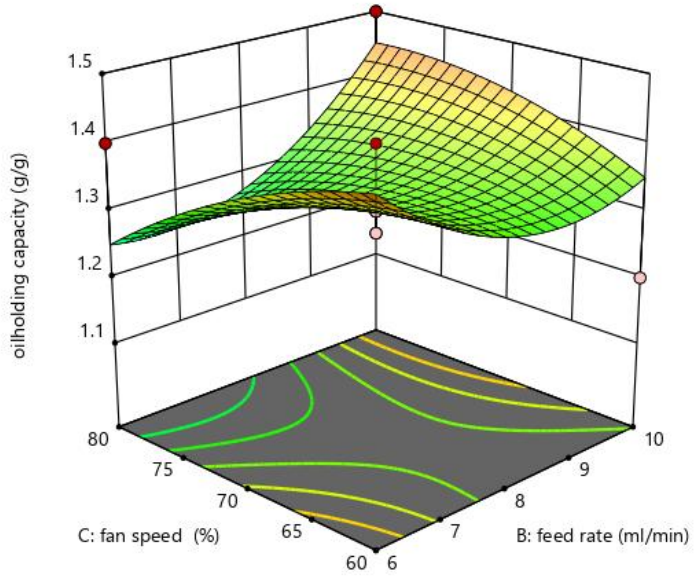
The mean model indicates that spray drying variables had no significant effect on OHC. Therefore, the best prediction for OHC is simply the average value of all experimental runs, regardless of inlet temperature, feed rate, or fan speed.


oilholding capacity (g/g)
1.5
1.4
1.3
1.2
1.1
10
9
8
7
6
B: feed rate (ml/min)
150
156
162
168
174
180
A: inlet temperature (c)

(a)


oilholding capacity (g/g)
1.5
1.4
1.3
1.2
1.1
80
75
70
65
60
C: fan speed (%)
150
156
162
168
174
180
A: inlet temperature (c)

(b)



(c)

Figure 8: 3D response surface plots showing the interaction effects of oil holding capacity (g/g)

4.1.7 Solubility

The solubility of the spray-dried papaya powders ranged from 83.67 ± 0.58% to 89.17 ± 0.06%. The ANOVA results for solubility indicated that the developed linear model (Appendix table 8) was significant ($p < 0.05$). Among the studied factors, inlet temperature had a significant effect ($p < 0.05$). This suggests that inlet temperature was the major factor affecting powder solubility. The solubility of the spray-dried powder generally increased with increasing inlet drying temperature from 150 °C to 180 °C. The highest solubility value was (89.17 ± 0.06%), while the lowest value was (83.67 ± 0.58%), indicating a comparatively longer dissolution time in water. The increase in solubility may be attributed to the formation of smaller and more porous particles at higher drying temperatures, which enhanced water penetration and dissolution capacity. The result of this study is in agreement with the findings of (Qadri *et a*l., 2023).

Higher inlet temperatures generally increase drying efficiency, reduce powder moisture content, and improve particle porosity, which enhances water penetration and dissolution of the powder.

However, excessively high inlet temperatures may reduce powder solubility due to caramelization or Maillard reactions during drying. In addition, the formation of a hard surface layer on powder particles at very high temperatures can limit water diffusion into the particles, thereby decreasing wettability and solubility. Similar observations were reported for spray-dried orange and watermelon juice powders by(George *et a*l., 2023). On the other hand, feed rate and fan speed were non-significant ($p > 0.05$), indicating that these factors did not substantially alter the structural characteristics of the powder within the studied range. This may be because the selected processing ranges were not wide enough to produce major differences in particle morphology or moisture removal rate, resulting in minimal changes in solubility.

Regression Equation for Solubility

$$S=86.21-1.54A-0.0750B-0.0375C$$

Where: S=solubility (%), A = Inlet air temperature, B = Feed flow rate and C = Fan speed

The negative coefficients of inlet air temperature, feed flow rate, and fan speed indicated that increasing these processing variables slightly reduced the solubility of the spray-dried papaya powder. Among the variables, inlet air temperature showed the greatest effect on solubility due to its larger negative coefficient.

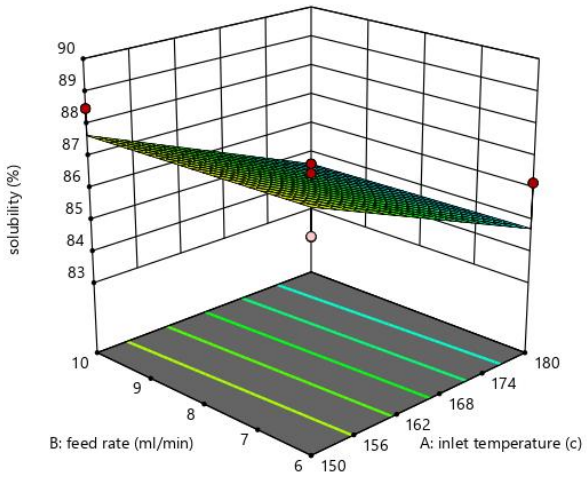


Figure 9: 3D response surface plots showing the interaction effects of the solubility (%)

4.1.8 Total Soluble Solid (TSS)

Total soluble solids (TSS) of the instant papaya powder ranged from 7.93 ± 0.12 to 9.10 ± 0.10 °Brix. Although the 2FI model was suggested because it showed comparatively better statistical adequacy than the linear model, the overall model (Appendix Table 9) remained statistically non-significant ($p > 0.05$), indicating limited predictive ability of the studied spray drying variables on TSS.

However, inlet temperature showed a significant individual effect on TSS, suggesting that temperature played a greater role in influencing soluble solid concentration than feed rate and fan speed. Increasing inlet drying temperature generally increased the TSS of the instant papaya powder, possibly due to rapid moisture evaporation during spray drying, which concentrated sugars and other soluble solids in the dried particles. The results of this study were within the range reported by (Phing & Saleena, 2022).

Regression Equation for Total Soluble Solids (TSS)

$$Y=+8.61 \quad +0.2500A+0.0000B+0.0250C+0.2250AB+0.2250AC-0.1250BC$$

Where: Y = Total soluble solids (°Brix), A = Inlet air temperature, B = Feed flow rate and C = Fan speed

The positive coefficient of inlet air temperature (A) indicated that increasing inlet air temperature slightly increased the total soluble solids of the spray-dried papaya powder. This agrees with the ANOVA result where inlet temperature was the only significant factor ($p < 0.05$). The increase in TSS at higher temperatures may be associated with rapid moisture evaporation and concentration of soluble solids during spray drying.

The coefficient of feed flow rate (B) was approximately zero, indicating that feed flow rate had minimal influence on TSS within the studied experimental range. Similarly, the positive coefficient of fan speed (C) suggested a slight increase in TSS with increasing fan speed. The positive interaction coefficients of AB and AC indicated that the combined effects of inlet air temperature with feed flow rate and fan speed slightly enhanced TSS. In contrast, the negative interaction coefficient of BC suggested that the combined effects of feed flow rate and fan speed slightly reduced TSS.

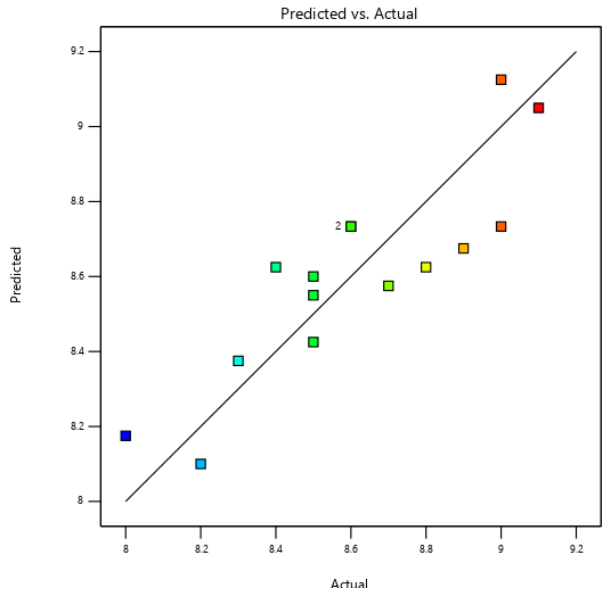


Figure 10: Predicted versus actual plot for total soluble solids (TSS) (°Brix)

4.1.9 Viscosity

The viscosity of the reconstituted powders produced from various processing conditions was ranged from 31.97±0.06cP to 44.87±0.23cP.

The ANOVA results for viscosity showed that the 2FI model (Appendix Table 10) was significant ($p < 0.05$), indicating that the spray drying processing conditions significantly affected the viscosity of instant papaya powder. Among the investigated variables, inlet temperature had a highly significant effect on viscosity ($p < 0.01$), while feed rate and fan speed showed non-significant effects ($p > 0.05$). The significant effect of inlet temperature suggests that increasing drying temperature influenced the viscosity behavior of the reconstituted powder, possibly due to changes in moisture removal, particle structure, and solubility characteristics during spray drying. The viscosity values obtained in the present study were higher than those reported by(L. S. Chang *et al*., 2022) , due to differences in fruit composition, drying conditions, and powder characteristics such as moisture content and soluble solid concentration, which can influence the rheological behavior of reconstituted powders.

The interaction effect between inlet temperature and feed rate was significant ($p < 0.05$), indicating that the combined effect of these two variables significantly influenced viscosity.

This is because simultaneous changes in drying temperature and feed flow rate altered droplet drying behavior and particle formation, thereby affecting the rheological properties of the reconstituted powder. However, the interaction effect between inlet temperature and fan speed, feed rate and fan speed interaction terms were non-significant, suggesting limited combined influence of fan speed with the other variables.

Regression Equation for Viscosity

Y= +38.67+3.37A-0.1250B+0.5000 C+3.00AB+1.75AC-1.25BC

Where:Y= viscosity (cP), **A** = Inlet air temperature, **B** = Feed flow rate and **C** = Fan speed

The regression equation indicated that inlet air temperature had the greatest positive effect on viscosity, as shown by its high positive coefficient. This agrees with the ANOVA results, where inlet temperature was found to be highly significant ($p < 0.05$).

Increasing inlet temperature generally increased viscosity, possibly due to enhanced moisture evaporation and concentration of soluble solids in the powder, which increased the thickness of the reconstituted product.

Feed flow rate showed a very small negative effect indicating that increasing feed rate slightly decreased viscosity, although the effect was statistically non-significant. Fan speed had a small positive effect, suggesting a slight increase in viscosity with increasing airflow. Among the interaction terms, the interaction between inlet temperature and feed flow rate showed the highest positive coefficient) and was statistically significant ($p < 0.05$), indicating that the combined increase of these variables enhanced viscosity.

The inlet temperature and fan speed interaction also showed a positive effect), while the feed rate and fan speed interaction had a negative effect, suggesting that simultaneous increases in feed rate and fan speed slightly reduced viscosity. Overall, the regression equation confirmed that inlet temperature was the major factor influencing viscosity of the instant papaya powder.

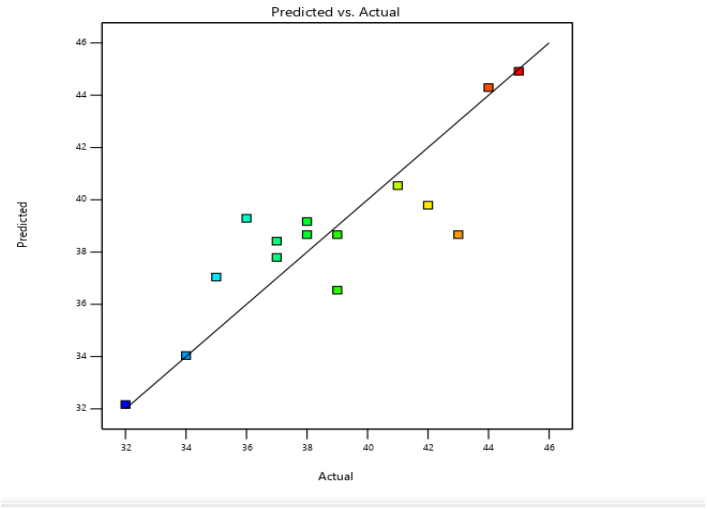


Figure 11: Predicted versus actual plot for viscosity (cP)

4.1.10 pH value

The pH values of the reconstituted powders produced under different spray-drying conditions ranged from 3.99 ± 0.53 to 4.47 ± 0.06.

The ANOVA results showed that the linear model (Appendix table 11) was significant ($p < 0.05$), indicating that the spray drying processing conditions significantly affected the pH. Among the investigated factors, inlet temperature had a highly significant effect ($p < 0.01$), whereas feed rate and fan speed were non-significant ($p > 0.05$). This suggests that inlet temperature was the major factor influencing the response variable.

The significant effect of inlet temperature is attributed to its strong influence on heat and mass transfer during spray drying. Increasing drying temperature generally accelerates moisture evaporation and alters powder particle formation, which can significantly affect the physicochemical properties of the powder. The pH values obtained in the present study were comparable with those reported by (Sharma *et al*., 2023). In contrast, feed rate and fan speed may not have caused sufficient changes in particle characteristics within the studied range to significantly affect the response.

Regression Equation for pH

$$Y=+4.27-0.1250A-0.0125B-0.0125C$$

Where: Y=power of hydrogen, A = Inlet air temperature, B = Feed flow rate and C = Fan speed

The negative coefficients of inlet air temperature, feed flow rate, and fan speed indicated that increasing these processing variables slightly reduced the pH of the spray-dried instant papaya powder. Among the variables, inlet air temperature showed the greatest influence on pH because it had the largest negative coefficient.

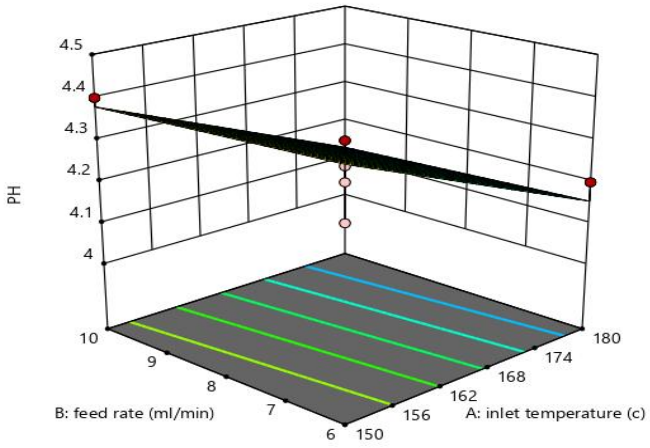


Figure 12: 3D response surface plot showing the effects of the pH

4.2 Sensory Quality Evaluation of Reconstituted Instant Spray-Dried Papaya Powder

Sensory evaluation was conducted to assess the acceptability of the reconstituted spray-dried instant papaya powder produced under different spray-drying conditions. The sensory attributes evaluated included color, flavor, aroma, taste, and overall acceptability.

Sensory qualities are the main criterion that makes a product to be liked or disliked (Wong *et al., 2023).* The sensory evaluation was conducted using a nine-point hedonic scale, where:1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely. The sensory scores for color, flavor, aroma, taste, and overall acceptability indicated that all products had mean values greater than 6, showing that the reconstituted papaya powder samples were generally liked by the panelists. Significant differences ($p <$

0.05) were observed among the treatments for the evaluated sensory attributes. Among the treatments, T6 showed the highest scores for most sensory attributes, including color (7.16±0.158), flavor (7.1±0.1), aroma (7.47±0.058), taste (7.1±0.1), and overall acceptability (7.22±0.016), indicating higher consumer preference for this treatment combination. In contrast, comparatively lower sensory scores were observed for treatments such as T3, T5, T7, and T12, although their scores still remained above the acceptable limit.

4.2.1 Color

The Color values of the reconstituted instant papaya powder were ranged from 6.01±0.153 to 4.47 ± 0.06. The ANOVA results indicated that the quadratic model (Appendix table 13) was significant ($p < 0.05$), Showing that the selected processing variables significantly affected the color response of the powder. Among the investigated variables, feed rate had a highly significant effect on ($p < 0.01$), indicating that feed flow rate was the dominant factor influencing the color quality of the spray-dried papaya powder. This is because feed rate affects droplet residence time and heat exposure during spray drying. At higher feed rates, incomplete drying and prolonged exposure to heat may promote pigment degradation and non-enzymatic browning reactions, thereby affecting the visual appearance of the powder (Süfer *et al*., 2025).

In contrast, inlet temperature and fan speed showed non-significant linear effects ($p > 0.05$). However, the quadratic term of feed rate (B^2) was significant ($p < 0.05$), indicating the presence of curvature in the response surface and suggesting that optimum feed rate levels existed for maintaining desirable color quality (Alizadeh Bahaabad et al., 2014). The quadratic effect of inlet temperature (A^2) was close to significant ($p = 0.0528$), implying that temperature may also influence color at certain processing ranges. The interaction effects (AB, AC, and BC) were non-significant ($p > 0.05$), indicating that the combined influence of inlet temperature, feed rate, and fan speed did not substantially affect the sensory color score. Overall, feed rate was identified as the most influential factor affecting the color acceptability of spray-dried instant papaya powder.

Regression Equation for Color

$Y=+7.00+0.1875A-0.4375B-0.1500C-0.1750AB+0.2000AC+0.0000BC-0.3125A^2-0.4625B^2-0.0375\ C^2$

Where: Y= Inlet air temperature, B = Feed flow rate and C = Fan speed

The regression equation indicated that feed flow rate had the greatest influence on the sensory color score because it had the largest coefficient magnitude among the linear terms. The negative coefficient of feed flow rate showed that increasing feed flow rate reduced the sensory color acceptability of the reconstituted instant papaya powder. This agrees with the ANOVA results, where feed rate showed a highly significant effect on color ($p < 0.01$).

The positive coefficient of inlet air temperature indicated that increasing inlet temperature slightly improved color scores, possibly due to improved drying efficiency and better retention of the characteristic papaya color at appropriate drying conditions. In contrast, the negative coefficient of fan speed suggested that increasing fan speed slightly reduced color acceptability. Among the interaction terms, the interaction between inlet temperature and fan speed positively influenced color, while the interaction between inlet temperature and feed flow rate slightly reduced the sensory color score. The BC interaction showed no effect because its coefficient was approximately zero.

The negative quadratic coefficients of A^2, B^2, and C^2 indicated curvature effects in the response surface, suggesting that extremely high or low processing conditions may reduce color quality, while moderate conditions may provide better sensory color acceptability.

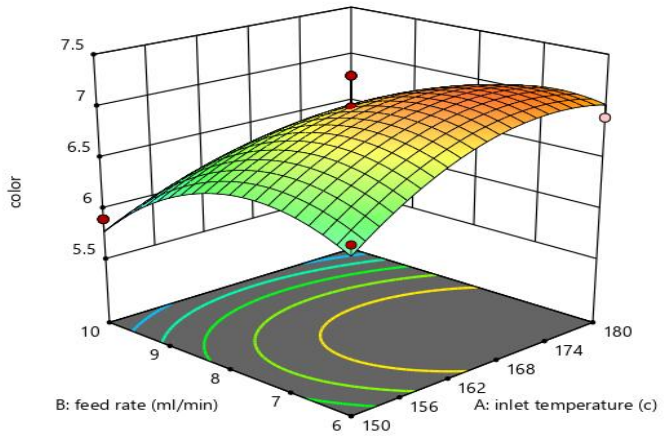


Figure 13: 3D response surface plot showing the interaction effects of color acceptability

4.2.2 Flavor

The Flavor values of the reconstituted instant papaya powder were ranged from 6.01±0.153 to 7.1 ± 0.01. The ANOVA results indicated that the quadratic model (Appendix table 14) was significant ($p < 0.05$), demonstrating that the selected processing variables significantly affected flavor acceptability. Among the investigated variables, feed rate (B) had a highly significant effect on flavor ($p < 0.01$), indicating that feed flow rate was the major factor influencing flavor acceptability of the reconstituted powder. This may be attributed to the influence of feed rate on droplet residence time and heat exposure during spray drying. Higher feed rates may reduce drying efficiency and promote incomplete drying, which can affect the retention of volatile flavor compounds and overall flavor perception. Similar findings were reported by (Qadri *et al*., 2023) who observed that optimized spray-drying conditions improved flavor retention and sensory acceptability of fruit powders by enhancing volatile compound stability and drying efficiency.

In contrast, inlet temperature and fan speed showed non-significant linear effects ($p > 0.05$). However, the quadratic term of feed rate (B^2) was significant ($p < 0.05$), indicating the presence of curvature in the response surface and suggesting that optimum feed rate levels existed for obtaining desirable flavor quality. The quadratic effect of inlet temperature (A^2) was close to significant ($p = 0.0787$), implying that inlet temperature may also influence flavor acceptability at certain processing conditions. The interaction effects (AB, AC, and BC) were non-significant ($p > 0.05$), indicating that the combined influence of inlet temperature, feed rate, and fan speed did not substantially affect flavor acceptability. Overall, feed rate was identified as the most influential processing variable affecting the flavor quality of the reconstituted spray-dried instant papaya powder.

Regression Equation for Flavor

$$Y=+6.80+0.2000A-0.3625B-0.1625C-0.1250AB+0.1750AC-0.0500BC-0.2750A^2-0.4500B^2+0.0000C^2$$

Where:Y = Inlet air temperature, B = Feed flow rate and C = Fan speed

The positive coefficient of inlet air temperature (A) indicated that increasing inlet air temperature slightly improved flavor acceptability of the reconstituted papaya powder. In contrast, the negative coefficients of feed flow rate (B) and fan speed (C) suggested slight reductions in flavor scores with increasing levels of these variables.

The negative interaction coefficients of AB and BC indicated that the combined effects of inlet air temperature with feed flow rate, and feed flow rate with fan speed slightly reduced flavor acceptability. However, the positive interaction coefficient of AC suggested that the combined effects of inlet air temperature and fan speed slightly enhanced flavor scores. Furthermore, the negative quadratic coefficients of A^2 and B^2 indicated decreasing curvilinear effects on flavor acceptability at higher levels of inlet air temperature and feed flow rate.

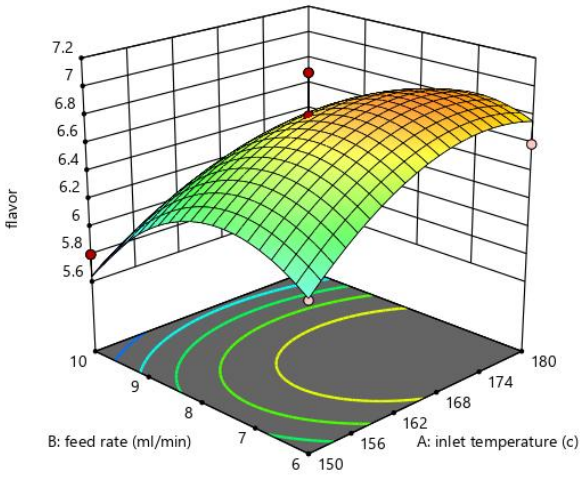


Figure 14: 3D response surface plot showing the interaction effects of flavor acceptability

4.2.3 Aroma

The aroma values of the reconstituted instant papaya powder were ranged from 6.07±0.208 to 7.47 ± 0.058. The ANOVA results showed that the quadratic model (Appendix table 15) was significant ($p < 0.05$), indicating that the selected processing variables significantly affected aroma acceptability. Among the investigated variables, feed rate (B) had a highly significant effect on aroma acceptability ($p < 0.05$), indicating that feed flow rate was the most influential processing parameter affecting aroma quality. This is attributed to the influence of feed rate on drying efficiency and retention of volatile aromatic compounds during spray drying. At higher feed rates, insufficient drying and shorter heat exposure may

alter the retention and release of aroma compounds, thereby affecting sensory aroma perception. Similar findings were reported by (Qadri *et al.*, 2023), who observed that optimized spray-drying conditions enhanced aroma retention and improved the sensory quality of fruit powders through better preservation of volatile compounds during drying.

In contrast, inlet temperature and fan speed showed non-significant linear effects ($p > 0.05$). However, the quadratic term of feed rate (B^2) was significant ($p < 0.05$), indicating curvature in the response surface and suggesting that optimum feed rate conditions existed for achieving desirable aroma quality. The quadratic effect of inlet temperature (A^2) was close to significant ($p = 0.0702$), implying that inlet temperature may also influence aroma acceptability under certain drying conditions. The interaction effects were all non-significant ($p > 0.05$), indicating limited combined influence of these variables on aroma acceptability. Overall, feed rate was identified as the major factor influencing the aroma quality of the reconstituted spray-dried instant papaya powder.

Regression Equation for Aroma

$$Y=+7.23+0.1875A-0.4250B-0.1625C-0.1250AB+0.1500AC-0.0750BC-0.2667A^2-0.4417B^2-0.0667C^2$$

Where: Y = Inlet air temperature, B = Feed flow rate and C = Fan speed

The positive coefficient of inlet air temperature (A) indicated that increasing inlet air temperature slightly improved the aroma acceptability of the reconstituted papaya powder. In contrast, the negative coefficients of feed flow rate (B) and fan speed (C) suggested slight reductions in aroma scores with increasing levels of these variables.

The negative interaction coefficients of AB and BC indicated that the combined effects of inlet air temperature with feed flow rate, and feed flow rate with fan speed slightly reduced aroma acceptability. However, the positive interaction coefficient of AC suggested that the combined effects of inlet air temperature and fan speed slightly enhanced aroma scores. Furthermore, the negative quadratic coefficients of A^2, B^2, and C^2 indicated decreasing curvilinear effects on aroma acceptability at higher levels of the processing variables.

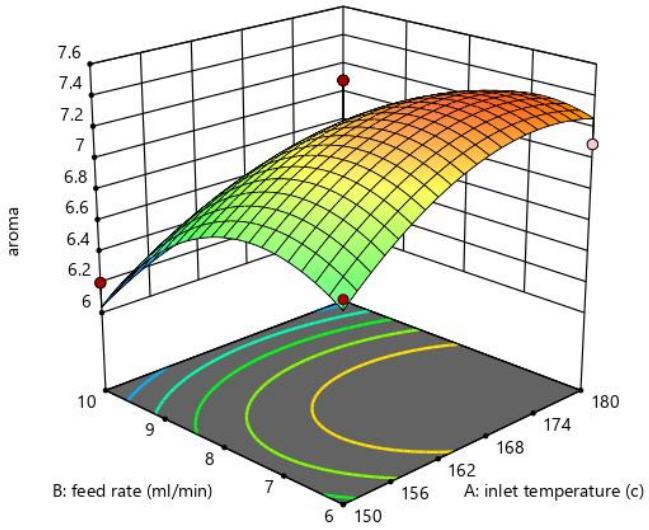


Figure 15: 3D response surface plot showing the interaction effects of aroma acceptability

4.2.4 Taste

The taste values of the reconstituted instant papaya powder were ranged from 6.01±0.058 to 7.1 ± 0.1. The ANOVA results indicated that the developed quadratic model (Appendix table 16) was statistically non-significant ($p > 0.05$). Among the investigated processing variables, feed rate (B) had a highly significant effect on taste acceptability ($p < 0.05$), indicating that feed flow rate was the major factor affecting sensory taste quality. This may be associated with the influence of feed rate on drying efficiency, moisture removal, and retention of flavor-related compounds during spray drying. Changes in feed flow rate can alter particle formation and concentration of soluble solids, which may directly influence taste perception of the reconstituted powder (Qadri *et al*., 2023) . In contrast, inlet temperature and fan speed showed non-significant linear effects ($p > 0.05$). The interaction effects (AB, AC, and BC) were also non-significant, indicating that the combined effects of the spray drying variables had limited influence on taste acceptability within the studied experimental range.

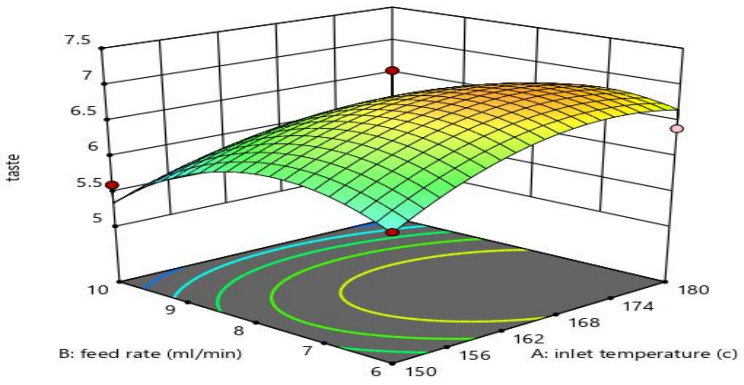
Regarding the quadratic effects, only the quadratic term of feed rate (B^2) was significant ($p < 0.05$), suggesting the presence of curvature in the response surface and indicating that optimum feed rate conditions existed for achieving desirable taste quality. The quadratic term of inlet temperature (A^2) was close to significance ($p = 0.0814$), implying that inlet temperature may also contribute to taste variation at certain drying condition.

Regression Equation for Taste

$Y=+6.80+0.2125A-0.4500B-0.2125C-0.1750AB+0.2500AC-0.0750BC-0.3750A^2-0.6000B^2+0.1250C^2$

Where: Y = Inlet air temperature, B = Feed flow rate and C = Fan speed

The positive coefficient of inlet air temperature (A) indicated that increasing inlet air temperature slightly improved taste acceptability of the reconstituted papaya powder. In contrast, the negative coefficients of feed flow rate (B) and fan speed (C) suggested slight reductions in taste scores with increasing levels of these variables. The negative interaction coefficients of AB and BC indicated that the combined effects of inlet air temperature with feed flow rate, and feed flow rate with fan speed slightly reduced taste acceptability. However, the positive interaction coefficient of AC suggested that the combined effects of inlet air temperature and fan speed slightly enhanced taste scores. Furthermore, the negative quadratic coefficients of A^2 and B^2 indicated decreasing curvilinear effects on taste acceptability at higher levels of inlet air temperature and feed flow rate, while the positive quadratic coefficient of C^2 suggested a slight increasing curvilinear effect of fan speed on



Taste

Figure 16: 3D response surface plot showing the interaction effects of taste acceptability

4.2.5 Overall acceptability

The sensory score of overall acceptability of the reconstituted spray-dried instant papaya powder were ranged from 6.01±0.079 to 7.22 ± 0.016. The ANOVA results showed that the

quadratic model (Appendix table 17) was significant ($p < 0.05$), indicating that the selected spray drying variables significantly affected the overall sensory acceptability of the product.

Feed rate (B) had a highly significant effect on overall acceptability ($p < 0.01$), indicating that feed flow rate was the most influential processing parameter affecting consumer preference of the reconstituted powder. This may be associated with the influence of feed rate on drying efficiency, particle formation, flavor retention, and reconstitution characteristics, which collectively contribute to the overall sensory perception of the product. The result of current study is in line with the result reported by (BHAGAWAN, 2015) .

In contrast, inlet temperature and fan speed showed non-significant linear effects ($p > 0.05$). However, the quadratic term of feed rate (B^2) was significant ($p < 0.05$), indicating curvature in the response surface and suggesting that optimum feed rate conditions existed for achieving maximum overall acceptability. The quadratic effect of inlet temperature (A^2) was close to significance ($p = 0.0873$), implying that inlet temperature may also contribute to sensory acceptability under certain drying conditions.

The interaction effects between inlet temperature and feed rate (AB), inlet temperature and fan speed (AC), and feed rate and fan speed (BC) were all non-significant ($p > 0.05$), indicating limited combined influence of the processing variables on overall acceptability within the studied experimental range. Overall, feed rate was identified as the major processing variable affecting the overall acceptability of the reconstituted spray-dried instant papaya powder.

Regression Equation for Overall Acceptability

$$Y=+6.97+0.2125A-0.4250B-0.1875C-0.1750AB+0.2000AC-0.0750BC-0.2833A^2-0.5083B^2+0.0167C^2$$

Where:Y =Overall Acceptability, A = Inlet air temperature, B = Feed flow rate and C = Fan speed

The positive coefficient of inlet air temperature (A) indicated that increasing inlet air temperature slightly improved the overall acceptability of the reconstituted papaya powder. In contrast, the negative coefficients of feed flow rate (B) and fan speed (C) suggested slight reductions in overall acceptability with increasing levels of these variables.

The negative interaction coefficients of AB and BC indicated that the combined effects of inlet air temperature with feed flow rate, and feed flow rate with fan speed slightly reduced overall acceptability. However, the positive interaction coefficient of AC suggested that the combined effects of inlet air temperature and fan speed slightly enhanced overall acceptability. Furthermore, the negative quadratic coefficients of A^2 and B^2 indicated decreasing curvilinear effects on overall acceptability at higher levels of inlet air temperature and feed flow rate, while the positive quadratic coefficient of C^2 suggested a slight increasing curvilinear effect of fan speed on overall acceptability.

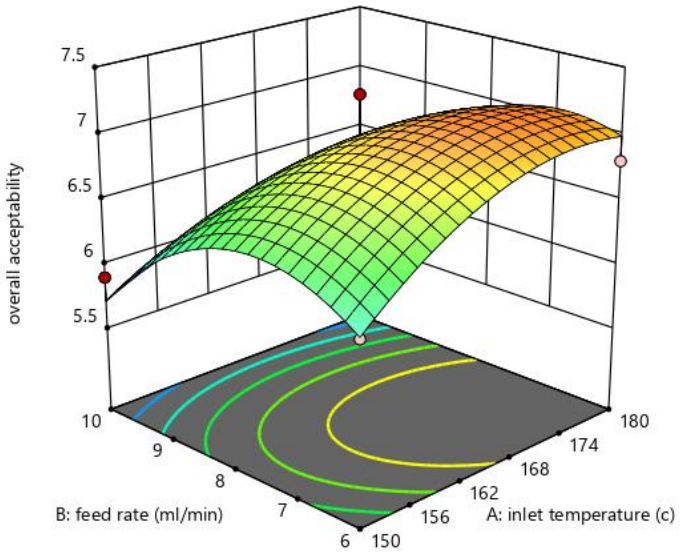


Figure 17: 3D response surface plot showing the interaction effects of overall acceptability

4.3 Overall Optimization of Spray Drying Conditions

The optimization process aimed to determine the optimum spray-drying conditions for producing instant papaya powder with desirable physicochemical properties and high overall acceptability (OAA). Response Surface Methodology (RSM) was employed to evaluate the combined effects of inlet air temperature, feed flow rate, and fan speed on the quality attributes of the powder. The optimization criteria were established to maximize process yield, solubility, water holding capacity (WHC), oil holding capacity (OHC), and overall acceptability, while minimizing moisture content and water activity. Bulk density, total soluble solids (TSS), viscosity, and pH were maintained within acceptable ranges. The overlay contour plot generated by Design-Expert software identified the optimum region,

represented by the yellow-colored area, where all response variables simultaneously satisfied the specified optimization criteria. Desirability values within the contour plot ranged from 0.2 to 0.8, with values closer to 1 indicating more desirable processing conditions. The optimum solution exhibited an overall desirability value of 0.818, indicating a high degree of agreement between the selected processing conditions and the desired quality characteristics of the powder.

The numerical optimization results identified the optimum spray-drying conditions as an inlet air temperature of 170.9°C, a feed flow rate of 7 mL/min, and a fan speed of 63%. Under these conditions, the developed models predicted a process yield of 79%, moisture content of 3.22%, water activity (aw) of 0.34, bulk density of 0.29 g/mL, solubility of 85.7%, and an overall acceptability score of 7.2. These optimized conditions produced powder with desirable physicochemical characteristics, good reconstitution properties, and high consumer acceptance, indicating its suitability for instant food applications.

The optimized spray-drying conditions and predicted quality responses obtained from RSM are presented in Table 4.2. The selected optimal solution was chosen because it exhibited the highest desirability value among all optimization solutions generated by Design-Expert software version 13.0.5.0.

Table 4: Optimized Spray-Drying Conditions and Predicted Quality Responses for Instant Papaya Powder

Sr.n	Variable/Response	Optimized Value
1	Inlet temperature (°C)	170.9
2	Feed rate (ml/min)	7.0
3	Fan speed (%)	63
4	Process yield (%)	79
5	Moisture content (%)	3.2
6	Water activity	0.34
7	Bulk density (g/ml)	0.29
8	Water holding capacity (g/g)	1.87
9	Oil holding capacity (g/g)	1.34
10	Solubility (%)	85.7

11	Total soluble solids (%)	8.5
12	Viscosity (cP)	38.2
13	pH value	4.2
14	Overall acceptability	7.2
15	Desirability	0.818

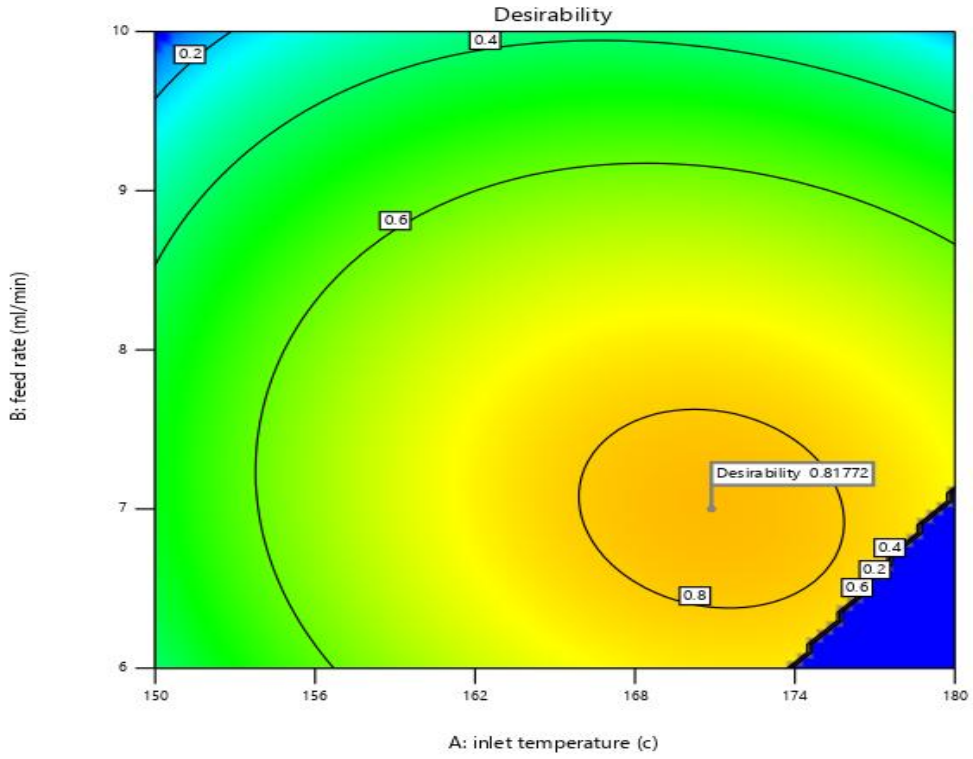


Figure 18: Overlay Contour Plot of the Optimization Region and Desirability Values for Spray-Dried Instant Papaya Powder

Based on the numerical optimization results, the optimum spray-drying conditions for the production of instant papaya powder were obtained at an inlet air temperature of 170.9°C, feed flow rate of 7 mL/min, and fan speed of 63%. Under these optimized conditions, the predicted responses were process yield of 79%, moisture content of 3.2%, water activity of 0.34, bulk density of 0.29 g/ml, water holding capacity of 1.87 g/g, oil holding capacity of 1.34 g/g, solubility of 85.7%, total soluble solids of 8.5%, viscosity of 38.2 cP, pH value of 4.2, and overall acceptability score of 7.2.

The optimization process generated an overall desirability value of 0.818, indicating that the selected spray-drying conditions were suitable for producing instant papaya powder with desirable physicochemical properties and acceptable sensory quality attributes.

Table 5: Comparison of Predicted and Experimental Response Values under Optimized Spray-Drying Conditions for Instant Papaya Powder

Response	Predicted Optimized Value	Actual Experimental Value	Percentage error = experiment- predict*100 predicted
Process yield (%)	79	82.0	3.797
Moisture content (%)	3.32	2.8	15.66
Water activity	0.34	0.31	8.82
Bulk density (g/ml)	0.29	0.28	3.45
WHC (g/g)	1.87	2.0	6.95
OHC (g/g)	1.34	1.2	10.45
Solubility (%)	85.7	86.2	0.58
TSS (%)	8.5	8.5	0
Viscosity (cP)	38.2	38	0.52
pH	4.2	4.2	0
OAA	7.2	7.22	0.28

The adequacy of the optimized spray-drying conditions obtained through Response Surface Methodology (RSM) was evaluated by comparing the predicted response values with the actual experimental values obtained from the experimental run conducted under optimized conditions. As presented in Table 4.4, the experimental values were reasonably close to the predicted responses for most quality attributes, indicating good agreement between the predicted and actual results.

The predicted process yield of 79% was comparable with the experimental value of 82.0%, suggesting efficient powder recovery under the optimized drying conditions. Similarly, the predicted moisture content (3.32%) and water activity (0.34) were close to the experimental values of 2.8% and 0.31, respectively, indicating desirable storage stability characteristics of the powder. The bulk density values also showed close agreement between the predicted and experimental results, confirming the reliability of the developed model.

Small variations were observed in water holding capacity, oil holding capacity, viscosity, and overall acceptability, which may be attributed to minor experimental and processing variations during spray drying and sensory evaluation. However, these deviations were within acceptable ranges and did not significantly affect the overall quality of the product. The experimental solubility (86.2%) and total soluble solids (8.5%) were also close to the predicted values, indicating good reconstitution properties of the instant papaya powder.

Overall, the close agreement between the predicted and experimental responses confirmed the adequacy, reliability, and suitability of the optimized RSM model for producing spray-dried instant papaya powder with desirable physicochemical and sensory quality characteristics.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study successfully optimized the spray-drying process conditions for the production of instant papaya powder using Response Surface Methodology (RSM). The approach effectively evaluated the effects of process variables and identified optimal operating conditions while minimizing the number of experimental runs required to obtain reliable results. The main variables were inlet air temperature, feed flow rate, and fan speed. The findings showed that these spray-drying conditions greatly impacted the physicochemical and sensory properties of the powder. Inlet air temperature and feed flow rate were the most important factors affecting powder quality. Fan speed had comparatively lower or non-significant effects on several responses. Higher inlet temperatures generally led to better process yield, solubility, and total soluble solids. They also reduced moisture content and water activity, which improved the powder's storage stability. However, excessively high temperatures harmed certain quality attributes, like water holding capacity and color stability in some treatments.

Feed flow rate consistently influenced both physicochemical and sensory properties. It affected drying efficiency, particle formation, and flavor retention. Lower feed rates often produce better-quality powder with improved drying efficiency and higher sensory acceptability. Fan speed had a moderate effect, mostly impacting drying air circulation and particle separation, but its influence was less significant than that of the other variables. The optimized conditions (inlet air temperature of about 170.9°C, feed flow rate of 7 mL/min, and fan speed of 63%) resulted in spray-dried papaya powder with desirable physicochemical characteristics. These included low moisture content (≈3.2%), low water activity (≈0.34), good solubility (≈85.7%), acceptable viscosity (≈38 cP), and high overall acceptability (≈7.2). The validation results showed a good match between predicted and experimental values, confirming the reliability of the developed models.

In summary, spray drying is an effective method for producing high-quality instant papaya powder suitable for instant beverage applications, with acceptable nutritional, functional, and sensory properties.

5.2 Recommendations

Product Utilization and Application: The optimized spray-dried instant papaya powder, produced at an inlet temperature of 170.9 °C, a feed flow rate of 7 mL/min, and a fan speed of 63%, demonstrated desirable physicochemical properties and good sensory acceptability. Therefore, it is recommended for use in the formulation of instant beverages, infant foods, and other functional food products.

Shelf-Life and Storage Stability Studies: Further research should investigate the storage stability of spray-dried papaya powder under different packaging materials and storage conditions, with particular emphasis on nutrient retention (especially vitamin C and β-carotene), antioxidant activity, and product quality over time.

Industrial Scale-Up and Technology Transfer: Relevant stakeholders, including FTVETIs, agricultural extension services, and food industries, should collaborate to facilitate the scaling up of the optimized spray-drying process from laboratory level to pilot and commercial production.

Economic Feasibility and Commercialization: Future studies should assess the economic feasibility of large-scale papaya powder production, including production costs, profitability, market demand, and commercialization potential in Ethiopia.

6 REFERENCES

Adeyi, O., Oke, E. O., Okolo, B. I., Adeyi, A. J., Otolorin, J. A., Nwosu-Obieogu, K., Adeyanju, J. A., Dzarma, G. W., Okhale, S., Ogu, D., & others. (2022). Process optimization, scale-up studies, economic analysis and risk assessment of phenolic rich bioactive extracts production from Carica papaya L. leaves via heat-assisted extraction technology. *Heliyon*, *8*(4).

Ahmad, S., Dolly Gupta, D. G., & Srivastava, A. K. (2013). *Studies on development, quality evaluation and storage stability of weaning food prepared from multipurpose flour, papaya powder and milk powder.*

Alara, O. R., Abdurahman, N. H., & Alara, J. A. (2020). Carica papaya: comprehensive overview of the nutritional values, phytochemicals and pharmacological activities. *Advances in Traditional Medicine*, 1–31.

Alizadeh Bahaabad, G., Gharibzahedi, S. M. T., Esmaiili, M., & Alizadeh, M. (2014). Response surface modeling for optimization of textural and color characteristics of dried grapes. *International Journal of Food Engineering*, *10*(3), 493–502.

Amunugoda, P., De Silva, A., Gunawardane, K. V, Pitipanaarchchi, R., Silva, A., & Dananjaya, G. T. (2020). Spray drying of ginger and physical and micro structural properties of spray dried ginger powder-an advance food material. *Front. Adv. Mater. Res.*, *2*(2), 9–17.

Anisuzzaman, S. M., Joseph, C. G., Nga, J. L. H., & Ismail, F. N. (2022). Effect of Carrier Agents and Operational Parameters on the Physical Quality of Spray-Dried Tomato Powder: A Review. *ASEAN Journal of Chemical Engineering*, 228–247.

Ankeli, J. A., Igbum, O. G., & Okibe, F. G. (2025). Comparative effects of drying methods on physicochemical properties of puree blends of some indigenous varieties of watermelon (Citrullus lanatus), orange (Citrus sinensis) and mango (Mangifera indica) fruits. *Journal of Agriculture, Aquaculture, and Animal Science*, *2*(1), 15–29.

Apichatwatana, N., Wongwan, S., Jongcharoenkamol, J., Kriangkrai, W., & Rujivipat, S. (2025). Box-Behnken design optimization of the spray-drying process for yield and antioxidant activity of Koklan remedy extract powder. *Science, Engineering and Health Studies*, 25050018.

Aravind, G., Bhowmik, D., Duraivel, S., & Harish, G. (2013). Health benefits and medicinal properties of Carica papaya. *Ann. Plant Sci*, *2*(2), 1–27.

Aryaee, H., Zare, D., Ariaii, P., Mirdamadi, S., & Raeisi, S. N. (2023). Production of a mixed fruit juice powder using mixture analysis and a fuzzy model. *International Food Research Journal*, *30*(4), 1049–1065.

Athira, V. A., Gokulvel, E., Nandhu Lal, A. M., Venugopalan, V. V, Rajkumar, & Venkatesh, T. (2023). Advances in drying techniques for retention of antioxidants in agro produces. *Critical Reviews in Food Science and Nutrition*, *63*(31), 10849–10865.

Athmaselvi, K. A., Kumar, C., Balasubramanian, M., & Roy, I. (2014). Thermal, structural, and physical properties of freeze dried tropical fruit powder. *Journal of Food Processing*, *2014*(1), 524705.

Ayele, L., Etissa, E., Dagnew, A., Assefa, W., Kebede, G., Girma, M., Firde, K., & Ayalew, M. (2017). Development of hermaphrodite papaya (Carica papaya L.) varieties for production in Ethiopia. *Academic Research Journal of Agricultural Science and Research*, *5*(7), 561–569.

Banothu, S. (2020). *Studies on integrated nutrient management on growth, yield, quality and effect of Post harvest treatments, Packaging materials on shelf life and quality of papaya (Carica papaya L.) cv. Red lady under southern Telangana*.

Barbosa, J. I. B. (2015). *Development of a functional orange juice powder by spray drying*. Universidade Catolica Portuguesa (Portugal).

Baruroh, D., Suselo, Y. H., Kusumawati, R., & Indarto, D. (2025). Effect of Freeze-Drying, Spray-Drying, and Foam-Mat-Drying Encapsulation Techniques on Vitamin C Level in Fruit Powder: A Scoping Review. *Journal of Health and Nutrition Research*, *4*(3), 1036–1047.

Benavides-Morán, A., Cubillos, A., & Gómez, A. (2021). Spray drying experiments and CFD simulation of guava juice formulation. *Drying Technology*, *39*(4), 450–465.

BHAGAWAN, M. R. J. M. (2015). *STUDIES ON PREPARATION OF POWDER FROM PAPAYA PULP BY USING SPRAY DRYER*. MAHATMA PHULE KRISHI VIDYAPEETH.

Binesh, N., Babaloo, H., & Farhadian, N. (2023). Microencapsulation: Spray drying. In *Principles of Biomaterials Encapsulation: Volume One* (pp. 271–296). Elsevier.

Burns, P., Saengmanee, P., & Doung-Ngern, U. (2022). Papaya: the versatile tropical fruit. In *Tropical Plant Species and Technological Interventions for Improvement*. IntechOpen.

Cabrera-Roque, D., Aragüez-Fortes, Y., Amador-Valladares, M., Rodríguez, J., & Pino, J. (2023). Optimization of spray-drying process for tomato paste. *Journal of Raw Materials to Processed Foods*, *4*(2).

Calliari, C. M., Shirai, M. A., Casazza, A. A., Pettinato, M., & Perego, P. (2024). Inulin as prebiotic encapsulating agent for the production of spray-dried Hibiscus sabdariffa L. tea microcapsules. *Natural Product Research*, *38*(19), 3311–3320.

Castañón Rodr\'\iguez, J. F., Uresti-Mar\'\in, R. M., Soto Gómez, M. G., Santiago-Adame, R., & Ortiz-Basurto, R. I. (2020). Evaluation of spray-drying{\'{}} s operable condition for obtaining orange juice powder: effects on physicochemical properties. *CyTA-Journal of Food*, *18*(1), 195–202.

Çelik, M., Muttil, P., Binzet, G., & Wendell, S. C. (2021). 161 Spray Drying and Pharmaceutical Applications. In *Handbook of Pharmaceutical Granulation Technology: Fourth Edition* (pp. 161–217). CRC Press.

Chan, W. S., Che Zain, M. S., & Ahmad Mokhtar, A. M. (2024). Microencapsulation of Elaeis guineensis leaf extract powder enriched with bioflavonoid preserves its antioxidant and anti-inflammatory properties: spray drying optimization and powder characterization. *Journal of Food Measurement and Characterization*, 1–20.

Chang, C.-L., McAleer, M., & Wong, W.-K. (2020). Risk and financial management of COVID-19 in business, economics and finance. In *Journal of Risk and Financial Management* (Vol. 13, Issue 5, p. 102). MDPI.

Chang, L. S., Ooi, Y. W., & Pui, L. P. (2022). Production of enzymatic hydrolysed spray-dried honeydew melon (Cucumis melo L.) powder. *Journal of Agriculture and Food Research*, *10*, 100364.

Chang, L. S., Tan, Y. L., & Pui, L. P. (2020). Production of spray-dried enzyme-liquefied papaya (Carica papaya L.) powder. *Brazilian Journal of Food Technology*, *23*, e2019181.

Da Silva, J. A. T., Rashid, Z., Nhut, D. T., Sivakumar, D., Gera, A., Souza, M. T., & Tennant, P. (2007). Papaya (Carica papaya L.) biology and biotechnology. *Tree and Forestry Science and Biotechnology*, *1*(1), 47–73.

Daley, O., Isaac, W.-A., John, A., & Kahramanoğlu, İ. (2023). Preharvest factors, maturity indices and postharvest physiology of fruits and vegetables. In *Postharvest physiology and handling of horticultural crops* (pp. 3–35). CRC Press.

Deshmukh, R., Wagh, P., & Naik, J. (2016). Solvent evaporation and spray drying technique for micro-and nanospheres/particles preparation: A review. *Drying Technology*, *34*(15), 1758–1772.

do Nascimento Remigio, M. S., Greco, T., Silva-Júnior, J.-O. C., Converti, A., Ribeiro-Costa, R. M., Rossi, A., & Barbosa, W. L. R. (2024). *Spray-Drying Microencapsulation of Phenolic Compounds from Bauhinia ungulata L. Var. Obtusifolia Aqueous Extract: A Comparative Study Using Different Wall Materials*.

Dotto, J. M., & Chacha, J. S. (2020). Scientific African. *Magnesium (Mg)*, *4*, 527–585.

Eghbal, N., Liao, W., Dumas, E., Azabou, S., Dantigny, P., & Gharsallaoui, A. (2022). Microencapsulation of natural food antimicrobials: Methods and applications. *Applied Sciences*, *12*(8), 3837.

FAO. (2018). *Guidelines on the Measurement of Harvest and Post− Harvest Losses: Recommendations on the Design of a Harvest and Post-Harvest Loss Statistics System for Food Grains (Cereals and Pulses)*. Food and Agriculture Organization (FAO) of the United Nations, REGNET (RAS ….

Farías-Cervantes, V. S., Salinas-Moreno, Y., Chávez-Rodríguez, A., Luna-Solano, G., Medrano-Roldan, H., & Andrade-González, I. (2020). Stickiness and agglomeration of blackberry and raspberry spray dried juices using agave fructans and maltodextrin as carrier agents. *Czech Journal of Food Sciences*, *38*(4).

Fathi, F., N. Ebrahimi, S., Matos, L. C., PP Oliveira, M. B., & Alves, R. C. (2022). Emerging drying techniques for food safety and quality: A review. *Comprehensive Reviews in Food Science and Food Safety*, *21*(2), 1125–1160.

Fikadu, T., & Etissa, E. (2025). Assessment of Field Management Practices of Smallholder Farmer's Avocado Production in the Major Areas of Ethiopia. *Journal of Agriculture, Food and Natural Resources*, *3*(I), 31–40.

Fitch, M. M. M. (2020). 6.1 Carica papaya Papaya. *Biotechnology of Fruit and Nut Crops*.

Gemeda, N., Yazew, T., Moroda, M., & Kuyu, C. G. (2025). Food safety practices and associated factors among food handlers in food establishments in Adama town, Central Ethiopia. *Frontiers in Sustainable Food Systems*, *8*, 1471429.

George, S., Thomas, A., Kumar, M. V. P., Kamdod, A. S., Rajput, A., T, J. J., & Abdullah, S. (2023). Impact of processing parameters on the quality attributes of spray-dried powders: A review. *European Food Research and Technology*, *249*(2), 241–257.

Ghalegi Ghalenoe, M., Dehnad, D., & Jafari, S. M. (2021). Physicochemical and nutritional properties of pomegranate juice powder produced by spray drying. *Drying Technology*,

39(12), 1941–1949.

Gil, P. J. R., & PESQUEIRA, M. C. (2023). *Caracterización genética y ambiental de poblaciones silvestres de papaya (Carica papaya L.) en su centro de origen*. Centro de Investigación Científica de Yucatán.

González-Oviedo, N. A., Fuentes-Ortíz, G., & Santamaría, J. M. (2025). Wild Carica papaya genotype is more waterlogging resilient than its commercial counterpart. *Theoretical and Experimental Plant Physiology*, *37*(1), 13.

Green Fields, G., & Pradesh, A. (2024). *Host Recognition for Survival of Plant Pathogens*.

Gulmez, H. B., Eroglu, E., & Topuz, A. (2021). Spray Drying Encapsulation of Minerals. In *Spray Drying Encapsulation of Bioactive Materials* (pp. 171–182). CRC Press.

Gunathilake, D., Tiwari, A. K., & Kahandawala, K. A. T. (2018). Efficacy of washing treatment for extending the post-harvest shelf-life of papaya (Carica papaya). *Int. J. Chem. Stud*, *6*, 2173–2177.

Gutema, T., & Tadesse, A. (2022). Assessment of post-harvest handling of mango and evaluation of mango jam in major mango producing areas of South Omo Zone, SNNPR, Ethiopia. *International Journal of Agricultural Research, Innovation and Technology (IJARIT)*, *12*(1), 155–160.

Hao, F., Fu, N., Ndiaye, H., Woo, M. W., Jeantet, R., & Chen, X. D. (2021). Thermotolerance, survival, and stability of lactic acid bacteria after spray drying as affected by the increase of growth temperature. *Food and Bioprocess Technology*, *14*, 120–132.

Hinostroza-Quiñonez, G., Alcántara-Mucha, L., Espinoza-Silva, C., Quispe-Solano, M., & Saavedra-Mallma, N. (2024). Physicochemical and functional properties of microcapsules of papaya seed extract (Carica papaya L.) obtained by spray drying. *NFS Journal*, *35*, 100164.

Jadhav, K., Kole, E., Singh, R., Rout, S. K., Verma, R. K., Chatterjee, A., Mujumdar, A., & Naik, J. (2024). A critical review on developments in drying technologies for enhanced stability and bioavailability of pharmaceuticals. *Drying Technology*, *42*(9), 1415–1441.

Jagdale, Y. (2025). *Effects of Electrostatic Spray Drying Encapsulation on Flavors and Its Comparison With Traditional Spray Drying*. University of Minnesota.

Jaskulski, M., & Wawrzyniak, P. (2024). Simulation and design of spray driers. In *Spray Drying for the Food Industry* (pp. 29–56). Elsevier.

Jiang, G., Ameer, K., Ramachandraiah, K., & Feng, X. (2024). Impact of water combined wet ball

milling extraction and functional evaluation of dietary fiber from papaya (Carica papaya L). *Food Chemistry: X*, *22*, 101435.

Jiang, Z., Zhang, M., Huang, Y., Ma, C., Mu, S., Li, H., Liu, X., Ma, Y., Liu, Y., & Hou, J. (2022). Comparison and characterization of the structure and physicochemical properties of three citrus fibers: Effect of ball milling treatment. *Foods*, *11*(17), 2665.

Johnson, G. I., & Hofman, P. J. (2009). Postharvest technology and quarantine treatments. *The Mango: Botany, Production and Uses*, 529–605.

Kader, A. A. (2013). Postharvest technology of horticultural crops-An overview from farm to fork. *Ethiopian Journal of Applied Science and Technology*, *1*, 1–8.

Kahramanoglu, I. (2023). *Postharvest Physiology and Handling of Horticultural Crops*. CRC Press.

Kebede, T. A. G. (2020). Facts of packaging materials and storage environment on post harvest quality of papaya (Carica papaya L.). *Journal of Biology, Agriculture and Healthcare*, *10*(1), 21–32.

Kim, J.-H., Kim, J. H., & Eun, J.-B. (2021). Optimization of spray drying process parameters for production of Japanese apricot (Prunus mume Sieb. et Zucc.) juice powder. *Food Science and Biotechnology*, *30*(8), 1075–1086.

Koç, G. Ç., & Dirim, S. N. (2018). Spray dried spinach juice: powder properties. *Journal of Food Measurement and Characterization*, *12*(3), 1654–1668.

Koul, B., Pudhuvai, B., Sharma, C., Kumar, A., Sharma, V., Yadav, D., & Jin, J.-O. (2022). Carica papaya L.: a tropical fruit with benefits beyond the tropics. *Diversity*, *14*(8), 683.

Kucharska-Guzik, A., Guzik, Ł., Charzyńska, A., & Michalska-Ciechanowska, A. (2025). Influence of freeze drying and spray drying on the physical and chemical properties of powders from Cistus creticus L. extract. *Foods*, *14*(5), 849.

Lamidi, S., Olaleye, N., Bankole, Y., Obalola, A., Aribike, E., & Adigun, I. (2022). *Applications of response surface methodology (RSM) in product design, development, and process optimization*. IntechOpen.

Lourenço, S. C., Moldão-Martins, M., & Alves, V. D. (2020). Microencapsulation of pineapple peel extract by spray drying using maltodextrin, inulin, and arabic gum as wall matrices. *Foods*, *9*(6), 718.

Magwaza, L. S., Opara, U. L., Nieuwoudt, H., Cronje, P. J. R., Saeys, W., & Nicola\"\i, B. (2012).

NIR spectroscopy applications for internal and external quality analysis of citrus fruit—a review. *Food and Bioprocess Technology*, *5*, 425–444.

Manik, S., Meena, G. S., Singh, A. K., Khetra, Y., Singh, R., Arora, S., & Vishweswaraiah, R. H. (2023). Valorization of sour buttermilk (a potential waste stream): conversion to powder employing reverse osmosis and spray drying. *Membranes*, *13*(9), 799.

Mart\'\inez-Navarrete, N., Garc\'\ia-Mart\'\inez, E., & Camacho, M. del M. (2022). Characterization of the orange juice powder co-product for its valorization as a food ingredient. *Foods*, *12*(1), 97.

Minuye, M., Getachew, P., Laillou, A., Chitekwe, S., & Baye, K. (2021). Effects of different drying methods and ascorbic acid pretreatment on carotenoids and polyphenols of papaya fruit in Ethiopia. *Food Science & Nutrition*, *9*(6), 3346–3353.

Nadali, N., Pahlevanlo, A., Sarabi-Jamab, M., & Balandari, A. (2022). Effect of maltodextrin with different dextrose equivalents on the physicochemical properties of spray-dried barberry juice (Berberis vulgaris L.). *Journal of Food Science and Technology*, *59*(7), 2855–2866.

Naik, B., Kumar, V., Goyal, S. K., Tripati, A. D., Khan, J. M., Irfan, M., Bhatt, S. C., Gupta, A. K., & Rustagi, S. (2023). Production, characterization, and application of novel fungal pullulanase for fruit juice processing. *International Journal of Biological Macromolecules*, *248*, 125936.

Nespi, M., Kuhn, R., Yen, C.-W., Lubach, J. W., & Leung, D. (2021). Optimization of spray-drying parameters for formulation development at preclinical scale. *AAPS PharmSciTech*, *23*(1), 28.

Nguyen, D. Q., Nguyen, T. H., & Allaf, K. (2022). Volumetric heat transfer coefficient in spray drying of soymilk powder. *Drying Technology*, *40*(6), 1146–1152.

Nguyen, D. Q., Nguyen, T. H., Mounir, S., & Allaf, K. (2018). Effect of feed concentration and inlet air temperature on the properties of soymilk powder obtained by spray drying. *Drying Technology*, *36*(7), 817–829.

Nguyen, M. (2022). Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (Momordica cochinchinensis) fruit aril powder. *Journal of Food Engineering*.

Nwosu-Obieogu, K., Oke, E., Chiamaka, U., Cyprian, D., Allen, M., Bright, S., Ohabuike, G., Goodnews, C., & Nwankwo, E. (2023). Journal of Agriculture and Food Research. *Journal of*

Agriculture and Food Research, *14*, 100746.

Oliveira, L. M. S., Silva, P. G., Silva, M. R. S., Cordeiro, D. A., Souza, L. P., Minafra, C. S., & Santos, F. R. (2022). Effect of moisture, particle size and thermal processing of feeds on broiler production. *Brazilian Journal of Poultry Science*, *24*(4), eRBCA-2020.

Ovando-Martínez, M., & González-Aguilar, G. A. (2020). Papaya. In *Nutritional composition and antioxidant properties of fruits and vegetables* (pp. 499–513). Elsevier.

Patra, J. K., Shin, H.-S., Yang, I.-J., Nguyen, L. T. H., & Das, G. (2024). Sustainable Utilization of Food Biowaste (Papaya Peel) Extract for Gold Nanoparticle Biosynthesis and Investigation of Its Multi-Functional Potentials. *Antioxidants*, *13*(5), 581.

Perera, H., Hosan, S., Wijesekara, D., Vithanage, V., & Koswattage, K. R. (2025). Development and characterization of a biodegradable pH indicator film using plant-based pigments. *Pharmaceuticals*, *11*, 17.

Pérez-Jiménez, J., & Saura-Calixto, F. D. (2017). Dietary Fiber and Associated Macromolecular Antioxidants in Fruit and Vegetables. *Fruit and Vegetable Phytochemicals: Chemistry and Human Health, 2nd Edition*, 393–404.

Phillips, K. M., McGinty, R. C., Couture, G., Pehrsson, P. R., McKillop, K., & Fukagawa, N. K. (2021). Dietary fiber, starch, and sugars in bananas at different stages of ripeness in the retail market. *PLoS One*, *16*(7), e0253366.

Phing, P. L., & Saleena, L. A. K. (2022). Effects of spray-drying parameters on physicochemical properties of powdered fruits. *Foods and Raw Materials*, *10*(2), 235–251.

Prasad, K., & Paul, J. R. (2021). Postharvest losses of papaya and practice for management. *Food Sci. Rep*, *2*(7).

Priyadarsini, S. (2020). *Effect of chemicals on shelf-life of Apple ber (Ziziphus mauritiana L.)*. Department of Fruit Science and Horticulture Technology, OUAT, Bhubaneswar.

Prusky, D. (2011). Reduction of the incidence of postharvest quality losses, and future prospects. *Food Security*, *3*, 463–474.

Pujapanda, R., Hamid, Bashir, O., Shams, R., Dash, K. K., Goksen, G., Shaikh, A. M., & Béla, K. (2025). Influence of carrier agents on nutritional, chemical, and antioxidant profiles of fruit juices during drying processes: a comprehensive review. *Discover Food*, *5*(1), 228.

Qadri, T., Naik, H. R., Hussain, S. Z., Bhat, T. A., Naseer, B., Zargar, I., & Beigh, M. A. (2023). Impact of spray drying conditions on the reconstitution, efficiency and flow properties of

spray dried apple powder-optimization, sensorial and rheological assessment. *Heliyon*, *9*(8).

Ranganath, K. G. (2022). Pigments that colour our fruits: An overview. *Erwerbs-Obstbau*, *64*(4), 535–547.

Riram, K., Maibam, P. S., Kumari, K., & Srikanth, P. (2024). Development of nutrition rich mixed fruit leather from Apple and Papaya: A review. *BIO Web of Conferences*, *110*, 2005.

Salgado-Aristizabal, N., Agudelo-Patino, T., Ospina-Corral, S., Álvarez-Lanzarote, I., & Orrego, C. E. (2023). Environmental life cycle analysis of acai (Euterpe oleracea) powders obtained via two drying methods. *Processes*, *11*(8), 2290.

Santana, A. A., Paixão, L. C., de Oliveira, R. A., & Telis, V. R. N. (2021). Influence of process conditions on the physicochemical properties of jussara pulp (Euterpe edulis) powder produced by spray drying. *CIÊNCIA E TECNOLOGIA DE ALIMENTOS: PESQUISA E PRÁTICAS CONTEMPORÂNEAS-VOLUME 2*, *2*, 517–536.

Sharma, R., Nath, P. C., & Seth, D. (2023). Optimization of spray-drying conditions using response surface methodology, physico-chemical characterization and shelf-life estimation of pineapple powder. *Sustainable Food Technology*, *1*(5), 750–761.

Singh, A., Rahman, M. A., Sharma, R., & Yemmireddy, V. (2021). Papaya ripeness and post-harvest storage conditions affect growth, survival and death kinetics of Salmonella and spoilage organisms. *Postharvest Biology and Technology*, *181*, 111659.

Singla, M., & Sit, N. (2024). Characterization of spray dried watermelon juice powder dried at different conditions and effect of incorporation of freeze-dried extract of papaya peel on phytochemical content of reconstituted juice. *Journal of Food Measurement and Characterization*, *18*(3), 1922–1932.

Süfer, Ö., Çal\i\cskan Koç, G., Öztekin, S., Özkan Karabacak, A., Su, D., Wang, D., Ero\uglu, S., Durgut Malçok, S., Uslu, Ü. H., Adal, S., & others. (2025). Evaluation of the effect of sustainable drying techniques and intensification technologies on color profile of dehydrated fruits and vegetables. *Food and Bioprocess Technology*, *18*(4), 3148–3194.

Tamime, A. Y. (2009). *Milk Processing and Quality Management*.

Tasmin, T. (2023). *COMPARATIVE EVALUATION OF NUTRITIONAL COMPONENTS, BIOACTIVE PROPERTIES AND ANTIBACTERIAL ACTIVITY OF PAPAYA (CARICA PAPAYA L.) SEED AT TWO STAGES OF RIPENING*. Chattogram Veterinary & Animal Sciences University, Khulshi, Chattogram.

Tetteh, H. (2022). *Convenience food and its packaging effect on human health a case study of Bantama market*. University of Education, Winneba.

Tolesa, G. N., Ademe, M. Y., & Workneh, T. S. (2023). Influence of evaporative coolant structures on the postharvest attributes of climacteric fruits. In *Evaporative Coolers for the Postharvest Management of Fruits and Vegetables* (pp. 29–40). Elsevier.

Ueda, J. M., Morales, P., Fernández-Ruiz, V., Ferreira, A., Barros, L., Carocho, M., & Heleno, S. A. (2023). Powdered foods: Structure, processing, and challenges: A review. *Applied Sciences*, *13*(22), 12496.

Uoorakkottil, I., Rashid, K., Annadurai, S., Ahmed, M. M., Rajagopal, A., & others. (2025). *Box--Behnken--Optimized Essential-Oil--Alcohol Hand Rub Shows in-vitro Activity Against SARS-CoV-2, Dengue, Influenza A, Measles, Chikungunya, and Nipah*.

Vega-Gálvez, A., Poblete, J., Rojas-Carmona, R., Uribe, E., Pastén, A., & Goñi, M. G. (2021). Vacuum drying of Chilean papaya (Vasconcellea pubescens) fruit pulp: Effect of drying temperature on kinetics and quality parameters. *Journal of Food Science and Technology*, *58*, 3482–3492.

Venkatram, P., & Pandiarajan, T. (2014). Optimization of ethylene concentration and exposure time for the ripening of mango var. Alphonso in farm level ripening chamber. *Trends in Biosciences*, *7*(24), 4259–4263.

Vicente, A. R., Manganaris, G. A., Darre, M., Ortiz, C. M., Sozzi, G. O., & Crisosto, C. H. (2022). Compositional determinants of fruit and vegetable quality and nutritional value. In *Postharvest handling* (pp. 565–619). Elsevier.

Wang, N., Wang, Y., Wang, X., Aslam, M. M., Li, W., & Shao, Y. (2025). Identification of xylanase (CpXYN1) gene and its role in promoting pulp softening during papaya fruit storage. *Scientia Horticulturae*, *342*, 114037.

Wang, Y., Liu, W., Li, L., Cao, W., Chen, J., Law, C. L., Ren, G., & Duan, X. (2026). Microbiological safety of dehydrated foods: risk analysis, technology evaluation, and synergistic strategies for next-generation processing. *Critical Reviews in Food Science and Nutrition*, 1–17.

Watson, A., Ghosh, S., Williams, M. J., Cuddy, W. S., Simmonds, J., Rey, M.-D., Asyraf Md Hatta, M., Hinchliffe, A., Steed, A., Reynolds, D., & others. (2018). Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature Plants*, *4*(1), 23–29.

Widowati, W., Pandanwangi, A., Zakaria, T. M., Kusumawaty, D., Wargasetia, T. L., Stefani, S., Kusuma, H. S. W., Zahiroh, F. H., Tyas, R. M., & Ayuni, V. (2024). Antioxidant Properties of Freeze Dried Mix Fruits and Vegetables Product ‘Miss Freezy’Using Lyophilization Method. *Journal of Nutrition and Food Security*, *9*(4), 721–732.

Wong, S. X., Jusoh, Y. M. M., Muhamad, I. I., & Hashim, Z. (2023). Formulation of Papaya Fruit Powder Incorporated Instant Drink Mix. *Journal of Bioprocessing and Biomass Technology*, *2*(1), 19–23.

Zeboon, N. H., & Baqir, H. A. A. (2022). The Role of Anti-Transpiration in Plant Growth. *Iraqi Journal of Soil Sciences*, *22*(2), 193–205.

Zhang, K., Wan, M., Bai, W., Bao, Z., Duan, X., Wang, W., Fan, F., & Li, Y. (2024). Optimization and scale-up of the spray drying process for Euglena gracilis. *Algal Research*, *82*, 103640.

7 APPENDICES

Appendix table 1: The effect of physicochemical properties of optimized spray-dried instant papaya powder

Trt	PY%	MC%	WA	BD g/ml	WHC g/g	OHC g/g	Sol (cP)	TSS%	Vis g/ml	pH
T1	72.27±0.25	4.87±0.058	0.42±0.01	0.31±0.01	2.2±01	1.39±0.01	86.67±0.58	8.49±0.02	36.8±0.26	4.3±0.1
T2	78.1±0.1	3.57±0.06	0.38±0.00	0.29±0.00	1.97±0.00	1.39±0.01	87.57±0.06	8.27±0.06	34.67±0.58	3.99±0.53
T3	74.47±0.06	3.27±0.56	0.35±0.00	0.3±0.01	1.99±0.01	1.4±0.2	83.67±0.06	9.1±0.1	44.87±0.23	4.07±0.06
T4	81.93±0.12	2.77±0.06	0.31±0.01	0.28±0.01	1.99±0.2	1.19±0.1	84.47±0.08	8.96±0.08	42.97±0.06	4.07±0.06
T5	66.9±0.17	5.03±0.06	0.46±0.01	0.33±0.01	2.27±0.06	1.07±0.06	89.17±0.06	7.93±0.12	33.7±0.61	4.47±0.06
T6	75.83±0.06	3.47±0.06	0.36±0.01	0.29±0.01	1.97±0.06	1.39±0.01	84.47±0.06	8.96±0.08	42.97±0.06	4.07±0.06
T7	68.3±0.61	4.27±0.06	0.41±0.01	0.32±0.01	2.29±0.02	1.49±0.02	86.48±0.03	8.49±0.02	36.32±0.59	4.27±0.06
T8	76.93±0.12	2.97±0.06	0.33±0.00	0.28±0.06	2.37±0.06	1.19±0.01	83.67±0.58	8.93±0.06	43.97±0.06	4.07±0.06

T9	76.07±0.06	3.57±0.06	0.36±0.00	0.30±0.01	2.07±0.06	1.3±0.01	86.78±0.02	8.63±0.06	37.98±0.04	4.29±0.01
T10	71.1±0.1	3.97±0.06	0.4±0.01	0.31±0.01	2±0.01	1.19±0.02	87.07±0.06	8.39±0.01	35.93±0.13	4.27±0.06
T11	75 ±0.1	3.39±0.01	0.35±0.01	0.329±0.01	2±0.01	1.29±0.01	86.41±0.08	8.59±0.01	38.99±0.02	4.19±0.01
T12	65.1±0.1	5.27±0.01	0.48±0.00	0.34±0.01	2.39±0.01	2±0.01	88.47±0.06	8.1±0.1	31.97±0.06	4.4±0.01
T13	75.17±0.06	3.7±0.01	0.39±0.01	0.29±0.01	2.19±0.01	1.39±0.02	85.3±0.0	8.87±0.06	40.67±0.58	4.18±0.02
T14	68.7±0.1	4.97±0.06	0.44±0.01	0.31±0.01	2.29±0.01	1.49±0.02	85.87±0.06	8.69±0.01	38.9±0.17	4.29±0.01
T15	80.2±0.1	2.93±0.06	0.32±0.01	0.28±0.01	1.77±0.06	1.28±0.02	84.73±0.06	8.83±0.01	41.67±0.58	4.20±0.01

Data are expressed as mean ± standard deviation (SD) of triplicate determinations (n = 3).

Where:

IT=Inlet Temperature FR=Feed Rate FS=Fan Speed PY=Process Yield MC=Moisture Content

WA=Water Activity BD=Bulk Density WH=Water Holding Capacity OHC=Oil Holding Capacity

Sol=Solubility TSS= Total Soluble Solid Vis =Viscosity pH=Power of hydrogen

Appendix table 2: Analysis of variance (ANOVA) for process yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	328.31	9	36.48	99.58	< 0.0001	significant
A-inlet temperature	204.02	1	204.02	556.92	< 0.0001	
B-feed rate	98.00	1	98.00	267.52	< 0.0001	
C-fan speed	13.00	1	13.00	35.50	0.0019	
AB	0.0100	1	0.0100	0.0273	0.8752	
AC	0.6400	1	0.6400	1.75	0.2435	
BC	0.1600	1	0.1600	0.4368	0.5379	
A^2	4.33	1	4.33	11.83	0.0184	
B^2	3.94	1	3.94	10.76	0.0219	
C^2	6.08	1	6.08	16.60	0.0096	
Residual	1.83	5	0.3663			
Lack of Fit	1.31	3	0.4350	1.65	0.3986	not significant
Pure Error	0.5267	2	0.2633			
Cor Total	330.14	14				

Appendix table 3: Analysis of variance (ANOVA) for moisture content

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	9.57	9	1.06	163.55	< 0.0001	significant
A-inlet temperature	8.41	1	8.41	1293.08	< 0.0001	
B-feed rate	0.4512	1	0.4512	69.42	0.0004	
C-fan speed	0.0313	1	0.0313	4.81	0.0798	
AB	0.0025	1	0.0025	0.3846	0.5623	
AC	0.0025	1	0.0025	0.3846	0.5623	
BC	0.0100	1	0.0100	1.54	0.2699	
A^2	0.4523	1	0.4523	69.59	0.0004	
B^2	0.1869	1	0.1869	28.76	0.0030	
C^2	0.1131	1	0.1131	17.40	0.0087	
Residual	0.0325	5	0.0065			
Lack of Fit	0.0125	3	0.0042	0.4167	0.7615	not significant
Pure Error	0.0200	2	0.0100			
Cor Total	9.60	14				

Appendix table 4: Analysis of variance (ANOVA) for water activity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.0380	9	0.0042	53.87	0.0002	significant
A-inlet temperature	0.0325	1	0.0325	415.05	< 0.0001	
B-feed rate	0.0021	1	0.0021	26.97	0.0035	
C-fan speed	0.0002	1	0.0002	2.55	0.1710	
AB	0.0000	1	0.0000	0.3191	0.5965	
AC	0.0000	1	0.0000	0.0000	1.0000	
BC	0.0000	1	0.0000	0.0000	1.0000	
A^2	0.0009	1	0.0009	11.20	0.0204	
B^2	0.0015	1	0.0015	19.65	0.0068	
C^2	0.0012	1	0.0012	15.13	0.0115	
Residual	0.0004	5	0.0001			
Lack of Fit	0.0003	3	0.0001	3.25	0.2441	not significant
Pure Error	0.0001	2	0.0000			
Cor Total	0.0384	14				

Appendix table 5: Analysis of variance (ANOVA) for bulk density

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.0046	9	0.0005	18.01	0.0027	significant
A-inlet temperature	0.0028	1	0.0028	99.26	0.0002	
B-feed rate	0.0015	1	0.0015	53.38	0.0008	
C-fan speed	0.0001	1	0.0001	1.76	0.2414	
AB	0.0000	1	0.0000	0.8824	0.3907	
AC	0.0001	1	0.0001	3.53	0.1191	
BC	0.0000	1	0.0000	0.0000	1.0000	
A^2	6.410E-07	1	6.410E-07	0.0226	0.8863	
B^2	0.0001	1	0.0001	2.74	0.1589	
C^2	0.0000	1	0.0000	0.5656	0.4859	
Residual	0.0001	5	0.0000			
Lack of Fit	0.0001	3	0.0000	0.7500	0.6148	not significant
Pure Error	0.0001	2	0.0000			
Cor Total	0.0047	14				

Appendix table 6: Analysis of variance (ANOVA) for water holding capacity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.4777	9	0.0531	22.75	0.0015	significant
A-inlet temperature	0.1250	1	0.1250	53.57	0.0007	
B-feed rate	0.0200	1	0.0200	8.57	0.0327	
C-fan speed	0.1800	1	0.1800	77.14	0.0003	
AB	0.0100	1	0.0100	4.29	0.0932	
AC	0.0900	1	0.0900	38.57	0.0016	
BC	0.0000	1	0.0000	0.0000	1.0000	
A^2	0.0433	1	0.0433	18.57	0.0076	
B^2	0.0003	1	0.0003	0.1099	0.7537	
C^2	0.0126	1	0.0126	5.38	0.0680	
Residual	0.0117	5	0.0023			
Lack of Fit	0.0050	3	0.0017	0.5000	0.7194	not significant
Pure Error	0.0067	2	0.0033			
Cor Total	0.4893	14				

Appendix table 7: Analysis of variance (ANOVA) for oil holding capacity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.0000	0				
Residual	0.2160	14	0.0154			
Lack of Fit	0.2093	12	0.0174	5.23	0.1715	not significant
Pure Error	0.0067	2	0.0033			
Cor Total	0.2160	14				

Appendix table 8: Analysis of variance (ANOVA) for solubility

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	18.97	3	6.32	3.87	0.0412	significant
A-inlet temperature	18.91	1	18.91	11.56	0.0059	
B-feed rate	0.0450	1	0.0450	0.0275	0.8713	
C-fan speed	0.0113	1	0.0113	0.0069	0.9354	
Residual	17.99	11	1.64			
Lack of Fit	14.86	9	1.65	1.06	0.5765	not significant
Pure Error	3.13	2	1.56			
Cor Total	36.96	14				

Appendix table 9: Analysis of variance (ANOVA) for Total Soluble Solids (TSS)

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.9725	6	0.1621	3.11	0.0705	not significant
A-inlet temperature	0.5000	1	0.5000	9.60	0.0147	
B-feed rate	0.0000	1	0.0000	0.0000	1.0000	
C-fan speed	0.0050	1	0.0050	0.0960	0.7646	
AB	0.2025	1	0.2025	3.89	0.0842	
AC	0.2025	1	0.2025	3.89	0.0842	
BC	0.0625	1	0.0625	1.20	0.3053	
Residual	0.4168	8	0.0521			
Lack of Fit	0.3102	6	0.0517	0.9693	0.5880	not significant
Pure Error	0.1067	2	0.0533			
Cor Total	1.39	14				

Appendix table 10: Analysis of variance (ANOVA) for Viscosity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	147.75	6	24.63	3.97	0.0383	significant
A-inlet temperature	91.12	1	91.12	14.70	0.0050	
B-feed rate	0.1250	1	0.1250	0.0202	0.8906	
C-fan speed	2.00	1	2.00	0.3227	0.5856	
AB	36.00	1	36.00	5.81	0.0425	
AC	12.25	1	12.25	1.98	0.1974	
BC	6.25	1	6.25	1.01	0.3447	
Residual	49.58	8	6.20			
Lack of Fit	35.58	6	5.93	0.8472	0.6304	not significant
Pure Error	14.00	2	7.00			
Cor Total	197.33	14				

Appendix table 11: Analysis of variance (ANOVA) for pH

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.1275	3	0.0425	5.45	0.0153	significant
A-inlet temperature	0.1250	1	0.1250	16.02	0.0021	
B-feed rate	0.0013	1	0.0013	0.1602	0.6966	
C-fan speed	0.0013	1	0.0013	0.1602	0.6966	
Residual	0.0858	11	0.0078			
Lack of Fit	0.0658	9	0.0073	0.7315	0.6969	not significant
Pure Error	0.0200	2	0.0100			
Cor Total	0.2133	14				

Appendix table12: Mean ± Standard Deviation of Sensory Scores for Spray-Dried Instant Papaya Powder

Trt	color	flavor	aroma	taste	overall acceptability
T1	6.2±0.1	6.067±0.058	6.6±0.1	6.01±0.058	6.22±0.038
T2	7.1 ±0.1	6.87±0.058	7.13±0.15	6.93±0.11	7.01±0.037
T3	6.02±0.1	6.04±0.153	6.07±0.208	6.1±0.152	6.1±0.025
T4	6.7±0.26	6.57±0.153	7.033±0.115	6.35±0.05	6.66±0.054
T5	6.03±0.153	6.1±0.115	6.3±0.1	6.04±0.55	6.14±0.053
T6	7.16±0.158	7.1±0.1	7.47±0.058	7.1±0.1	7.22±0.016
T7	6.01±0.153	6.01±0.153	6.2±0.100	6.01±0.051	6.06±0.079
T8	6.82±0.231	6.7±0.173	7.133±0.153	6.83±0.112	6.87±0.089
T9	6.93±0.110	6.77±0.058	7.13±0.121	6.42±0.380	6.81±0.060
T10	6.13±0.115	6.1±0.1	6.489±0.080	6.09±0.364	6.20±0.141
T11	6.6±0.1	6.5±0.1	7.03±0.060	6.19±0.511	6.58±0.116
T12	6.02±0.1	6.01±0.053	6.13±0.115	6.09±0.631	6.06±0.172
T13	6.63±0.153	6.67±0.058	7±0.173	6.76±0.055	6.77±0.075
T14	6.49±0.080	6.56±0.069	6.79±0.101	6.72±0.59	6.64±0.0.074
T15	6.87±0.058	6.71±0.102	7.133±0.153	6.90±0.035	6.90±0.042

Data are expressed as mean ± standard deviation (SD) of triplicate determinations (*n* =3).

Where: Trt = Treatment

Appendix table 13: Analysis of variance (ANOVA) for color

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	3.35	9	0.3723	6.59	0.0257	significant
A-inlet temperature	0.2812	1	0.2812	4.98	0.0761	
B-feed rate	1.53	1	1.53	27.10	0.0034	
C-fan speed	0.1800	1	0.1800	3.19	0.1343	
AB	0.1225	1	0.1225	2.17	0.2009	
AC	0.1600	1	0.1600	2.83	0.1532	
BC	4.441E-16	1	4.441E-16	7.860E-15	1.0000	
A^2	0.3606	1	0.3606	6.38	0.0528	
B^2	0.7898	1	0.7898	13.98	0.0134	
C^2	0.0052	1	0.0052	0.0919	0.7740	
Residual	0.2825	5	0.0565			
Lack of Fit	0.1025	3	0.0342	0.3796	0.7814	not significant
Pure Error	0.1800	2	0.0900			
Cor Total	3.63	14				

Appendix table 14: Analysis of variance (ANOVA) for flavor

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	2.75	9	0.3055	5.31	0.0403	significant
A-inlet temperature	0.3200	1	0.3200	5.57	0.0648	
B-feed rate	1.05	1	1.05	18.28	0.0079	
C-fan speed	0.2113	1	0.2113	3.67	0.1134	
AB	0.0625	1	0.0625	1.09	0.3449	
AC	0.1225	1	0.1225	2.13	0.2042	
BC	0.0100	1	0.0100	0.1739	0.6940	
A^2	0.2792	1	0.2792	4.86	0.0787	
B^2	0.7477	1	0.7477	13.00	0.0154	
C^2	0.0000	1	0.0000	0.0000	1.0000	
Residual	0.2875	5	0.0575			
Lack of Fit	0.1075	3	0.0358	0.3981	0.7714	not significant
Pure Error	0.1800	2	0.0900			
Cor Total	3.04	14				

Appendix table 15: Analysis of variance (ANOVA) for aroma

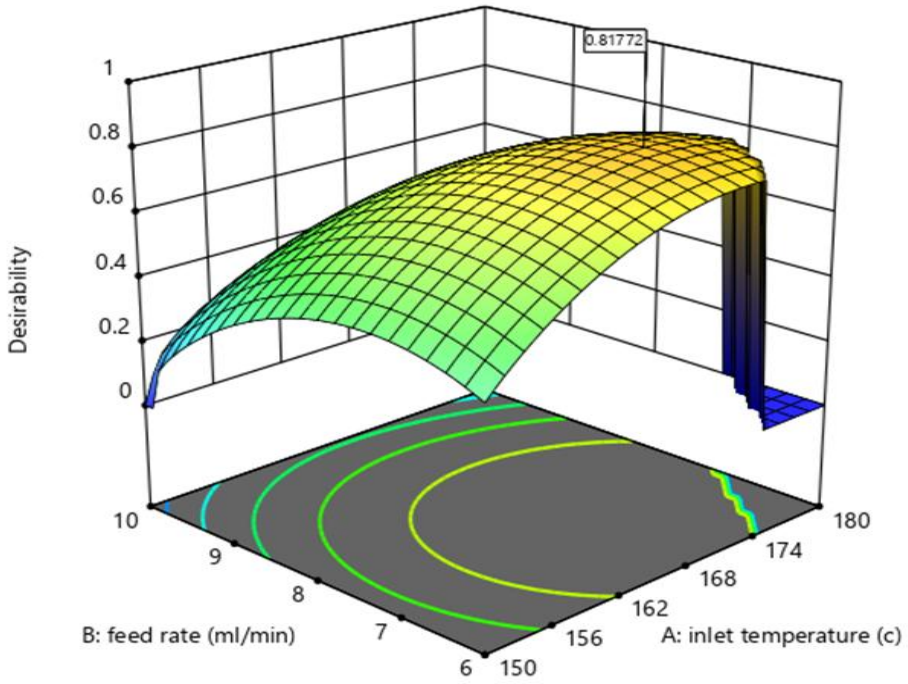
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	3.03	9	0.3372	6.77	0.0243	significant
A-inlet temperature	0.2812	1	0.2812	5.64	0.0635	
B-feed rate	1.45	1	1.45	29.00	0.0030	
C-fan speed	0.2113	1	0.2113	4.24	0.0946	
AB	0.0625	1	0.0625	1.25	0.3136	
AC	0.0900	1	0.0900	1.81	0.2367	
BC	0.0225	1	0.0225	0.4515	0.5314	
A^2	0.2626	1	0.2626	5.27	0.0702	
B^2	0.7203	1	0.7203	14.45	0.0126	
C^2	0.0164	1	0.0164	0.3293	0.5909	
Residual	0.2492	5	0.0498			
Lack of Fit	0.1225	3	0.0408	0.6447	0.6553	not significant
Pure Error	0.1267	2	0.0633			
Cor Total	3.28	14				

Appendix table 16: Analysis of variance (ANOVA) for taste

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	4.61	9	0.5122	4.68	0.0520	not significant
A-inlet temperature	0.3613	1	0.3613	3.30	0.1290	
B-feed rate	1.62	1	1.62	14.79	0.0120	
C-fan speed	0.3613	1	0.3613	3.30	0.1290	
AB	0.1225	1	0.1225	1.12	0.3386	
AC	0.2500	1	0.2500	2.28	0.1912	
BC	0.0225	1	0.0225	0.2055	0.6693	
A^2	0.5192	1	0.5192	4.74	0.0814	
B^2	1.33	1	1.33	12.14	0.0176	
C^2	0.0577	1	0.0577	0.5269	0.5005	
Residual	0.5475	5	0.1095			
Lack of Fit	0.2875	3	0.0958	0.7372	0.6195	not significant
Pure Error	0.2600	2	0.1300			
Cor Total	5.16	14				

Appendix table 17: Analysis of variance (ANOVA) for overall acceptability

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	3.59	9	0.3987	6.06	0.0307	significant
A-inlet temperature	0.3612	1	0.3612	5.49	0.0662	
B-feed rate	1.45	1	1.45	21.95	0.0054	
C-fan speed	0.2812	1	0.2812	4.27	0.0936	
AB	0.1225	1	0.1225	1.86	0.2307	
AC	0.1600	1	0.1600	2.43	0.1797	
BC	0.0225	1	0.0225	0.3418	0.5842	
A^2	0.2964	1	0.2964	4.50	0.0873	
B^2	0.9541	1	0.9541	14.49	0.0125	
C^2	0.0010	1	0.0010	0.0156	0.9055	
Residual	0.3292	5	0.0658			
Lack of Fit	0.1425	3	0.0475	0.5089	0.7152	not significant
Pure Error	0.1867	2	0.0933			
Cor Total	3.92	14				



Appendix figure1: 3D Desirability Surface Plot for Spray-Dried Instant Papaya Powder





Appendix figure2: Sample Preparation for Spray Drying of Instant Papaya Powder



Appendix figure 3: Spray dryer setup



Appendix Figure 4: Photograph of Panelists performing sensory evaluation of instant papaya powder



Appendix figure 5: Photo of instant papaya powder

Appendix table18: Sensory Evaluation Score Sheet

Product Name: Optimized Spray-Dried Instant Papaya Powder

Product code:

Panelist Number: _____

Date: _____

Instructions

Please taste each sample carefully and evaluate it based on the sensory attributes listed below. Indicate your level of liking or disliking using the 9-point hedonic scale provided.. Assign the score that best represents your opinion for each attribute. Water is provided to rinse your mouth between samples.

9-Point Hedonic Scale

Score	Description
9	Like Extremely
8	Like Very Much
7	Like Moderately
6	Like Slightly
5	Neither Like nor Dislike
4	Dislike Slightly
3	Dislike Moderately
2	Dislike Very Much
1	Dislike Extremely

Sensory Evaluation Form

Sample code	Sensory quality attributes				
	Color	Flavor	Aroma	Taste	Overall Acceptability
314					
582					
147					
693					
428					
751					
269					
835					
194					
647					
523					
786					
351					
908					
472					

Comments/Suggestions

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