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Secondary Packaging Performance Assessment Based on Mechanical Damage Resistance Using Drop Testing and Forensic Packaging Methods at CV. Mubarokfood Cipta Delicia

Rheznandya Gaffi Rangga Saputra[1] and Thalia Naziha[*,1]
[1]Department of Agroindustrial Technology, Faculty of Agricultural Technology Universitas Gadjah Mada, Jl. Flora No.1 Bulaksumur 55281, Indonesia.
Email: thalianaziha@ugm.ac.id*

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Abstract

Distribution is a process that could decrease the quality of food products biologically, chemically, and physically. Therefore, food packaging plays a crucial role in extending the shelf life and maintaining the quality and safety of food products. This research aims to gather evidence on packaging damage data that can be used to evaluate the effectiveness of product packaging, considering its durability and ability to protect products, and to understand the impact of packaging damage on product quality. Data collection was carried out by observing the packaging chosen as a research sample, specifically 9 Mubarok's Jenang secondary slop packaging. Each package contains 4 Jenang inside, so there were 36 Mubarok's Jenang in total. The author also conducted interviews to obtain relevant information about the topics in this section, including packaging, quality control, and the purchasing division. Drop testing and forensic packaging methods were performed manually by dropping the item from a fixed height onto a solid, hard, and flat surface, as specified in ISO 2248:1985. Based on the research result after testing from three variations of drop height (50 cm, 100 cm, 150 cm) with each height containing three sample packages, all of the packaging is in a "good" category, which is proven by the value of bruise susceptibility parameter is very low, packaging damage is in the light category, and the product's primary packaging is still tightly sealed so that it can maintain the quality and shelf life of Jenang during the retention period. Then, consecutively, the average values and their deviations for the bruise susceptibility of the packaging at heights of 50 cm, 100 cm, and 150 cm are 0.0549 cm³/Joule, 0.0735 ± 0.0164 cm³/Joule, and 0.0699 ± 0.0214 cm³/Joule.

Keywords: *bruise susceptibility, drop testing, flip carton, forensic packaging, Jenang*

1. INTRODUCTION

CV Mubarokfood Cipta Delicia is a company that produces *Jenang* Kudus, located at Glantengan Village, Kota District, Kudus Regency. *Jenang* is one of the traditional Indonesian dishes, especially in Javanese cuisine. Jenang Mubarok, produced by CV Mubarok Cipta Delicia, is a brown, chewy, and sweet treat made from brown sugar, coconut milk, and sticky rice flour. CV Mubarokfood Cipta Delicia company offers various types of packaging, categorized into several levels, including primary packaging, secondary packaging, tertiary packaging, and quaternary packaging. Primary packaging is a package that directly covers or wraps food ingredients. Secondary packaging is a package whose main function is to protect other packaging groups (containing several primary packaging groups). Furthermore, tertiary and quaternary packaging are additional types of packaging beyond primary and secondary packaging. This packaging is typically used during distribution to storage locations or final destinations, such as consumers (Aditri et al., 2021).

Within this research, we will produce several outputs that are useful for the company. The first step is to establish a standard for the packaging material used by the company, which encompasses several attributes and parameters derived from testing results, particularly for the type of cardboard packaging that contains the *Jenang* product (ASTM D5639M-20, 2025). This output also correlates with the main objective of implementing this project. Secondly, the test result can be used to respond to negative feedback from consumers regarding Jenang Mubarok products in terms of durability and packaging (Emblem, A., & Emblem, H, 2012). The third output is to know and evaluate endurance and packaging ability to protect the product (Lengas et al., 2023). Lastly, we test the impact of mechanical damage on the *Jenang* product, specifically looking for any bruising that may cause a decrease in quality.

In the world of industry and forensics, research related to drop testing and the development of forensic packaging is vital. Based on Emblem, A., & Emblem, H. (2012), drop testing and forensic packaging can ensure product integrity during distribution and their benefits in reducing product damage. By understanding the importance of drop testing and forensic packaging techniques, it is hoped that this research will make a significant contribution to the development of manufacturing packaging durability test methods, as well as to reducing mechanical damage and improving packaging for a variety of contents, ranging from industry to the forensic world.

2. MATERIAL AND METHODS

This research method uses quantitative research methods. This research was conducted from January 2 to February 1, 2024. This research was also conducted at CV Mubarokfood Cipta Delicia located in Kudus, Central Java, Indonesia. The study is conducted in two company units: production units within the packaging division, collaborating with the research and development (R&D) division, as well as the quality control unit (QC). The objects observed in this research are secondary slop packaging of Jenang Mubarok products, specifically in the form of folding cartons, at CV. Mubarokfood Cipta Delicia. This secondary packaging features a structure made from duplex paper that exhibits a characteristic color difference between its layers. The inside layer is a darker color (grey) than the outside layer (white), which is usually used as a printing area in one sheet of duplex paper.

Based on observations, the authors collected information about each level of packaging, as shown in Table 1. Furthermore, additional information about materials, characteristics, suppliers, and other relevant details was obtained from interviews with the head of the purchasing department and the head of the packaging department.

Table 1. Specification About Mubarok's Jenang Product & Packaging of Each Level

Product & Packaging		Specification		Characteristic
Jenang Product		Sample Variance	Smooth mocha flavored	1. Smooth, Chewy, and Elastic Texture. *Jenang* has a soft texture, is not too sticky, and is chewy when eaten. 2. Long Shelf Life. *Jenang* has a longer shelf life due to a well-controlled and long cooking process. 3. Tempting Brown Color. A blend of coffee and chocolate flavors gives *Jenang* its distinctive brown color and enticing aroma. 4. Traditionally Packaged. Packaged by BOPP plastic film and wrapped in the signature of Kudus *Jenang* packaging.
		Production Date	08-01-2024	
		Mass	20 gram	
		Size	5.5 x 2 x 2 cm	
		Materials	Glutinous rice flour, coconut milk, and sugar	

Product & Packaging		Specification		Characteristic
Primary Package (BOPP Film)		Mass	0.1 gram	1. Transparent & Glossy. It has a clear and shiny appearance, giving it a premium look. 2. Strong & Tear-Resistant. Highly durable against tearing and pressure 3. Water & Oil Resistant. Does not get easily damaged by moisture or liquids 4. Easy to Print On. Suitable for high-quality printing with sharp and long-lasting colors 5. Lightweight & Flexible. Easily shaped to fit various packaging needs 6. Eco-friendly. It can be recycled, although it requires a typical process 7. Widely Used. It is commonly used for food packaging, beverages, pharmaceutical products, and labeling on bottles.
		Size	8 x 8 cm	
		Capacity	1 film for each *Jenang*	
		Final Process	Wrapping	
		Material	biaxially oriented polypropylene (BOPP)	
Secondary Package Specification	  	Mass	7.192-7.49 gram	1. It consists of two different layers. One white (smoother) for high-quality printing, and the other grey (rougher) 2. Medium strength. Stronger than HVS paper but not as sturdy as cardboard or corrugated board 3. Eco-Friendly. Often made from recycled materials, making it more environmentally friendly. 4. Affordable. Cheaper than other packaging materials like plastic or cardboard
		Size	11.3 x 5.4 x 2.1 cm	
		Capacity	4 *Jenang* pieces	
		Product Placement	2x2 (Horizontal)	
		Product Proportion	91.291-91.8501%	
		Final Process	Folding	
		Material	Duplex Paper	
		Outside Layer Color	White (for printing layer)	
		Inside Layer Color	Grey	
Tertiary Package (Duplex Paper)		Size	27.5 x 11.6 x 4.5 cm	Similar to secondary packages
		Capacity	10 pieces of secondary	
		Packaging	40 pcs *Jenang*	
		Amount	5x5 (Vertical)	
		Product Placement	Folding	
		Final Process	Duplex Paper	
		Material	White (for printing layer)	
		Outside layer color	Grey	

Data collection was conducted using both primary and secondary data. This research some primary data is needed for this research, such as drop testing and forensic packaging experiment results on packaging and data on packaging damage after it occurs impact, packaging material characteristics (mechanical properties and material resistance packaging against pressure, friction, and impact strength), simulation conditions (parameters such as drop height and environmental conditions during the drop test and time retention), and forensic data (information resulting from forensic analysis of damaged packaging including traces and signs of damage). Furthermore, for secondary data, several data needed for this research, such as scientific journal that discusses characteristics of packaging and its impact on the product, packaging specifications (information from the manufacturer packaging regarding materials, design, and technical limitations), industry statistics (history shipping or distribution accident statistics that can provide insight about packaging vulnerabilities), and packaging guidelines (guidelines or standards industry related to testing and packaging safety criteria).

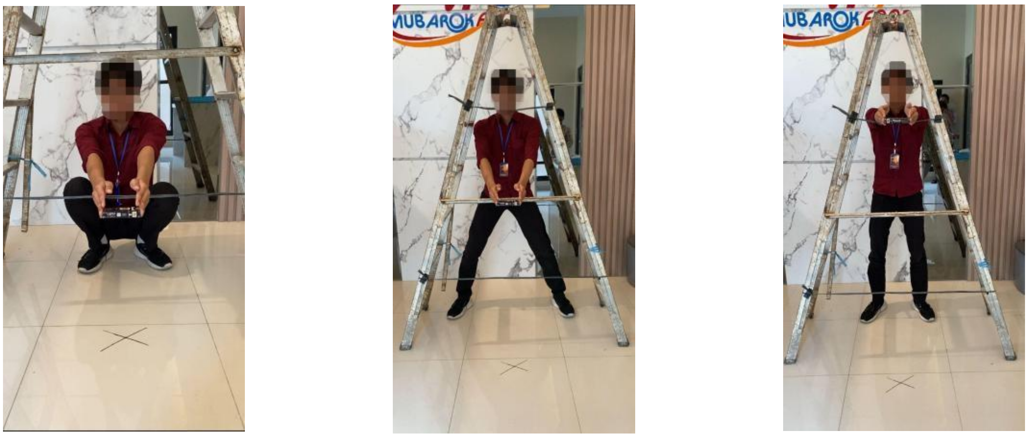
As mentioned earlier, the authors selected several respondents, including the head of QC & R&D, the head of purchasing, and the head of the packaging division, to gather information about product and packaging specifications. Based on information obtained from the head of QC & R&D, it can be concluded that several factors affecting defects in *Jenang* products are the activity of water and airflow. *Jenang* products contain an enzyme called lipoxygenase, which is typically found in products made from coconut milk. Water activity can explain why the lipoxygenase enzyme is active when in contact with water, allowing for the formation of brown color in semi-moist food (intermediate moisture food), such as *dodol* (Kusnandar, 2019). Airflow that contains oxygen (O_2) also activates enzymes during the production, storage, or handling process. These two factors can directly affect the product if the product's primary packaging (BOPP) isn't sealed correctly, resulting in gaps in the packaging that expose the product directly.

The authors also gathered information from the head department of purchasing and packaging about the specification of the packaging materials, characteristics, third-party suppliers, packaging resistance due to mechanical damage, existing standard parameters of packaging (if any), and the main point of how often buyers or consumers give feedback or complain about packaging resistance. Furthermore, the authors have arranged Table 1 to display the specifications of the product and packaging. Based on the ISTA 1A procedure, cartons and products weighing less than 10 kg are dropped from a minimum height of 76 cm (30 inches). The authors created three height variations within a 76 cm range to ensure the result was significant and multifunctional, representing the real condition. There was no certainty whether the conditions, product, and sample were dropped from a height of 76 cm. The first height fall of 50 cm represents material handling conditions when laborers are packaging products using a table, and 50 cm reflects the distance between the table surface and the floor. A second height fall of 100 cm represents material handling conditions when load-in and load-out processes are carried out on distribution vehicles, where many workers are found to be carrying out inappropriate material handling actions (dropping & throwing). A height of 150 cm represents whether a product displayed at a shopping outlet can withstand being dropped to test the durability of the packaging. Data processing in this research is carried out using drop testing and forensic packaging methods analysis from 3 different heights within three samples of each drop fall:

2.1 Drop Testing

Drop testing, also known as packaging drop test, is a test process used to measure the extent to which a package, product, or object can withstand damage when falling from a specified height. Drop testing is a type of testing designed to assess a package's ability to resist damage (Lengas et al., 2023). Thus, drop testing is an important tool in packaging development and testing to ensure product safety, quality, and durability.

The working principle of packaging drop testing, which is carried out manually without the use of a tool, involves testing the dropping of goods at a fixed point and specific angles and heights in accordance with existing regulations (Pratama et al., 2018). In this experiment, the packaging will be dropped in a horizontal position (0 ° angle), referring to its arrangement in the tertiary packaging, to observe how the drop position of the packaging changes. Figures 1a-c show that the packaging will be dropped at each height.



(a) (b) (c)

Figure 1. Packaging Drop Testing Illustration in Each Height Fall (a) 50 cm (b) 100 cm (c) 150 cm

Several regulations serve as references, including ASTM D5276-98, which outlines packaging testing standards that incorporate drop tests and forensic packaging methods. Based on ASTM D5276-98, each product container that is under 50 kg must comply with ISO 2206:1987 for the segmented areas on packaging samples, ISO 2248:1985, and ISTA 1A for the procedure of the testing, and ISO 2233:1996 for the retention control time, as the bruise may affect the quality degradation of the product. When carrying out drop testing, the packaging box is more likely to land on the rib or packaging point when dropped with the eccentricity of the center of gravity (Nica et al., 2023). The packaging box will absorb the force and only transfer it to a limited extent to these products. When the packaging has fallen to the ground, it will have obtained maximum kinetic energy after experiencing maximum potential energy at a certain height before being dropped. Such a condition is what is known as the law of conservation of energy in mechanics. The maximum kinetic energy will be absorbed by the material, causing the packaging to deform or break. The amount of energy that the material can absorb before experiencing deformation is a measure of the material's resistance. Material is considered tough if it can absorb large shock loads without easily experiencing deformation. This test is based on the potential energy absorption of the load dropped vertically to a certain height until the specimen experiences deformation. The amount of energy absorbed by the specimen until it fractures is a measure of the material's impact resistance (Rifqoh, 2016). The mechanical energy (impact energy) that hits each package is calculated. The impact energy that is absorbed by the packaging samples after experiencing a collision is calculated using the equations (1) and (2).

$$\text{Impact Energy (J)} = \text{Potential Energy} = m.g.h \quad (1)$$

or

$$\text{Impact Energy (J)} = \text{Kinetical Energy} = \tfrac{1}{2}.m.v^2 \quad (2)$$

By using three samples of secondary packaging to drop at each height, the standard deviation of impact energy absorbed at each height must be determined to allow us to know the error value of the measurements using the formula (3).

$$\text{Impact Energy Absorbed Standard Deviation (50 cm; 100 cm; 150 cm)} = \frac{\sqrt{\sum(xi-x)^2}}{n-2} \quad (3)$$

Where:

xi : value of impact energy absorbed at a certain height in the i-repetition

x : average value impact energy absorbed at a certain height

n : number or value of repetition

In addition, the damage level to the packaging parts on the sides, corners, and ribs is calculated to obtain the percentage of damage to the parts and determine critical points of the packaging with the equation (4), (5), and (6).

$$\text{Percentage of damage to the sides} = \frac{\text{Number of Damaged Sides}}{\text{Number of Packaging Sides}} \times 100\% \quad (4)$$

$$\text{Percentage of damage to the ribs} = \frac{\text{Number of Damaged Ribs}}{\text{Number of Packaging Ribs}} \times 100\% \quad (5)$$

$$\text{Percentage of damage to corners} = \frac{\text{Number of Corners Sides}}{\text{Number of Corners Sides}} \times 100\% \quad (6)$$

2.2 Retention Control Time

The ISO 2233:1996 standard regulates control behavior during packaging and product retention time. Factors include air humidity. At room temperature (27 °C or 300 K), the Rh value is maintained at 65%. Retention time, also known as residence time, aims to determine the impact of mechanical testing on the quality characteristics of *Jenang* products due to the bruising they cause. Additionally, check for any extensive bruising on the product and packaging. Retention time during drop testing also aims to ensure that the product or material being tested can survive under specific conditions for a specified period. It is essential to understand how well products and materials can withstand the impact of falls over time, ensuring their safety in everyday use.

2.3 Forensic Packaging

Forensic packaging is a method used to determine the cause of failure or damage to the packaging that causes the product to fail, resulting in packaged products suffering losses (such as decreased quality and physical defects) (Waszkiewicz, 1991). Forensic packaging methods can be a useful tool for determining the success or failure of certain packaging features. Forensic packaging can also be useful as a development tool in determining the potential success and failure of tamper-proof packaging features.

The working principle of forensic packaging is to determine bruises, which is defined as a ratio of bruise volume to internal energy or energy absorbed by the product. This value is expressed in the amount of damage per unit of energy, internal or absorbed energy, that is commonly used to measure potential damage. Observations are conducted through manual inspection, machine vision assistance, and microscopic imaging. With this approach, the bruise volume estimation model is based on the width and depth of the bruise. Then, an incision is made on the surface of the bruised product to form an ellipse to the depth of the bruise. Sample slicing was performed after the sample was left in the laboratory at 25 °C for 24 hours, following the drop test, to allow the product bruising to spread (Du et al., 2019)

Forensic packaging analysis started after products and packaging samples had passed the retention control period. Each package and product will be identified if any bruising appears after drop testing. On the packaging, the sliced part was chosen based on the area with the highest percentage of bruising that occurs after drop testing and the retention time control period. Then, the dimensions of the bruise that has been sliced are identified, starting from the length of the bruise (w1), the width of the bruise (w2), and the depth of the bruise (db). This variable is used to determine the bruise area and bruise volume of the packaging, and the packaging bruise susceptibility (BS) value is determined by calculating the ratio between the impact energy of the packaging and its bruise volume. According to Du et al. (2019), forensic packaging involves several equations used to derive results from the analysis, as shown (7), (8), and (9).

$$\text{Bruise Area (cm}^2\text{)} = \frac{\pi.w1.w2}{4} \quad (7)$$

$$\text{Bruise Volume} = \frac{\pi.db}{4} \times (3.w1.w2 + 4.db^2 \quad (8)$$

$$\text{Bruise Susceptibility (cm}^3\text{/Joule)} = \frac{Bruise\ Volume}{Impact\ Energy} \quad (9)$$

However, because the samples used at each height are of three types, the bruise susceptibility value for each height fall must be determined using the standard deviation formula (10).

$$\text{Bruise Susceptibility Standard Deviation (50 cm; 100 cm; 150 cm)} = \frac{\sqrt{\sum(xi-x)^2}}{n-2} \quad (10)$$

Where:

xi : value of bruise susceptibility at a certain height in the i-repetition

x : average value of bruise susceptibility at a certain height

n : number or value of repetition

3. RESULTS AND DISCUSSION

The samples used in this research were packaging samples of foldable cardboard-based secondary or more with a flip carton. The secondary slop packaging used is made of duplex paper, which can be identified due to differences in color on the packaging layer. On layers, the inside has a gray or darker color and a rough surface. Then, the outer layer is a white layer, which can be used for image printing because it has a smooth surface and is slippery. In packaging printing, duplex paper is a type of high-quality packaging cardboard because it can produce text, and the printed image will be sharper, especially when equipped with a high-tech printing machine. Furthermore, the duplex paper raw material has a layer side. The back is thick enough to make this paper last longer and better under certain conditions. In terms of strength, duplex paper exhibits characteristics such as resistance to tearing, impact resistance, heat resistance, and resistance to sunlight (Paramita, 2015).

The use of slop secondary packaging as a test sample in this study was due to research limitations. In this research, the testing method was carried out manually without the use of tools, namely by dropping goods at various points, angles, and heights in accordance with existing rules. This limitation means that researchers cannot calculate the value of energy absorbed from the packaging to the product because the more layers there are and the higher the level of packaging that protects the product, the impact energy when it falls will be absorbed into the packaging material in each layer, and it is possible that it will not hit the product and prevent the packaging is deformed. Additionally, the use of secondary packaging for testing samples will facilitate the collection and processing of data. Manual testing methods are unable to calculate the energy absorbed in each package that is packaged for higher packaging levels, resulting in uncertainty about whether the energy that hits the package will be distributed evenly across all packages or concentrated in certain ones. Therefore, in this study, secondary slop packaging was chosen, each packaging containing 4 *Jenang* products, which had been packaged in primary packaging made from BOPP (biaxially oriented polypropylene) plastic. By testing this slop secondary packaging, the mechanical energy that hits the packaging will have a damaging effect on both the packaging in terms of durability and the product in terms of quality, as the sample directly packages the product.

The implementation of this test is based on packaging testing standards, including drop tests and forensic packaging methods, as outlined in ASTM D5276-98. The drop test applies to product containers weighing less than 50 kg, so they must comply with ISO 2206:1987, which specifies the division of packaging areas into quadrants based on their shape. For packages or packaging in the form of packaging. Parallelogram beams or parallelepiped packages, such as packaging forms. In this experiment, the packaging area was divided based on the numbering of each side of the packaging. Figures 2a-d illustrate the classification of packaging areas and their implementation.

(a) (b) (c) (d)

Figure 2. Illustration and Implementation View of Packaging Areas Classification Based on ISO 2206:1987 (a) Illustration of Packaging (b) Top View (c) Right Side View (d) Front View

Sample packaging is divided into 3 parts that identify the sides, edges, and angles of the packaging. On the sides, there are symbols in the form of capital letters from "A" to "F", based on the number of sides of the packaging, there are 6 pieces. On the ribs, symbols are indicated in the form of numbers 1 to 12, corresponding to the number of ribs in the package, totaling 12. Then, the corners are assigned the letters A to H according to the number of corners on the package, totaling 8. Packaging is also assigned a sample code to facilitate more straightforward naming. Table 2 shows that the packaging sample code is used based on the repetition and height of the test.

Table 2. Information on the Drop Height Test and Sampling Code

No	Test Height (cm)	Sample Code (Repetition Height)
1	50	1.1 2.1 3.1
2	100	1.2 2.2 3.2
3	150	1.3 2.3 3.3

Based on the ISTA 1A procedure, cartons and products weighing less than 10 kg are dropped from a minimum height of 76 cm (30 inches). The weight of the secondary packaging itself ranges from 7 to 7.5 grams per package. However, in this test, three height variations were used: 50 cm, 100 cm, and 150 cm. Three height variations were used to ensure that the data and results of this research were more multifaceted, as there was uncertainty about whether consumers, employees, or even third-party companies would drop the packaging at a height of 76 cm. Therefore, by testing packaging at various heights, the research results can be more comprehensive, and the quality of the packaging in terms of resistance to mechanical damage at specific heights can be determined.

The number of packages tested at each height is 3 samples, allowing for statistical analysis.

This research focuses on the ability of packaging to protect products from mechanical damage during testing. *Jenang* products are packaged in primary packaging, namely BOPP (biaxially oriented polypropylene) plastic. BOPP (or OPP) plastic is a plastic film that is widely used for plastic packaging purposes in the food and beverage industry, cigarettes, pharmaceuticals, detergents, shampoo, garments, cosmetics, and so on. BOPP film is made from polypropylene resin and other synthetic chemicals, making BOPP plastic a material that is difficult to decompose naturally (Santoso and Widyamurti, 2019). Furthermore, the author presents an indicator for assessing packaging resistance to mechanical damage based on several parameters in Table 3.

Table 3. Assessing Indicators for Packaging Resistance to Mechanical Damage

No	Primary Packaging Conditions (BOPP)	Secondary Packaging Conditions (Flip Carton)	Packaging Assessment Indicators
1	Not Damaged	Not Damaged	Very Good
2	Not Damaged	Damaged	Good
3	Damaged	Not Damaged	Poor
4	Damaged	Damaged	Very Poor

Park et al (2013) outlined that packaging damage can be assessed at the packaging seal. For example, a package that isn't tightly sealed or opened has a significant impact on food safety. This condition allows the entry of air, microorganisms, and other contaminants that can facilitate pathogen growth and degradation of product quality (Park et al., 2013). Defects in *Jenang* products are organoleptically noticeable due to the BOPP plastic being open, allowing more air and water to enter. Excess air and water can affect food stability and durability, as well as chemical reaction rates, enzyme activity, and microbial growth, which are typically influenced by water activity (Aw). Water activity can explain why the lipoxygenase enzyme is active when in contact with water, allowing for the formation of brown color in semi-moist food (intermediate moisture food), such as *dodol* (Kusnandar, 2019). Organoleptic defects commonly found in *Jenang* products include a hardened texture due to shelf-life aging, the appearance of mold due to excessive water activity, and contamination from air, which can occur if the primary packaging is opened. Therefore, this research focuses on the packaging's ability to protect the product's primary packaging from being opened, thereby minimizing the amount of water and air entering the product.

The implementation of drop testing is regulated in ISO 2248:1985, which regulates the technical Implementation of drop tests (surface selection, procedures, working principles, and test reporting). According to ISO 2248:1985, the working principle of the drop testing method is to lift the test sample above a rigid plane surface and release it to impact a specific packaging surface (impact surface) after undergoing a free-fall motion. Atmospheric conditions, fall height, and control treatments were carried out at the start of the test. Griffin et al. (1985) stated that in drop testing, the packaging must be dropped on a flat and sturdy surface.

3.1 Drop Testing

Drop testing was conducted using a total of 9 packaging samples, with 3 samples at each height drop of 50 cm, 100 cm, and 150 cm. Each package can pack up to 4 pieces of *Jenang,* so the required number of Jenang samples is 36, which have been assigned a number. During testing, the room temperature was maintained at 27 °C to ensure optimal conditions. The packaging that is dropped first is the 50 cm packaging in sequence, which is 1.1, 2.1, to 3.1, followed by heights of 100 cm and 150 cm. Next, the packaging is inspected on each side, rib, and corner, and any new bruises are noted after drop testing. Results from drop testing are summarized in Table 4, which provides information obtained after the drop testing.

Table 4. Sample Packaging Drop Testing Result

Height (cm)	Sample Code	Product + Packaging Mass (g)	Impact Energy Absorbed (J)	Std. Deviation of Impact Energy (J)	Number of Bruises After Testing (Packaging)	Percentage Increase in Packed Bruise
50	1.1	86.333	0.420	0.004	1 (Corner H)	12.5% (Corner)
	2.1	87.316	0.428		1 (Rib 5)	8.333% (Rib)
	3.1	85.685	0.420		4 (Rib 3, 5, 9, 10) 3 (Corner A, C, E)	33.333% (Rib) 37.5% (Corner)
100	1.2	86.737	0.850	0.022	1 (Corner G)	12.5% (Corner)
	2.2	85.388	0.836		1 (Corner A) 3 (Rib 3, 5, 11)	12.5% (Corner) 25% (Rib)
	3.2	89.745	0.880		3 (Corner A, B, C)	37.5% (Corner)
150	1.3	87.866	1.292	0.039	1 (Rib 5) 2 (Corner A, E)	8.333% (Rib) 25% (Corner)
	2.3	83.558	1.230		1 (Rib 3) 2 (Corner A, E)	8.333% (Rib) 25% (Corner)
	3.3	88.590	1.302		1 (Rib 3) 3 (Corner A, D, H)	8.333% (Rib) 37.5 (Corner)

Based on the results obtained from drop testing, it can be concluded that the critical point for packaging on the ribs is rib 5, and on the corners, it is corner A. This is because this section experiences the most damage in each sample test. However, after passing an inspection on the *Jenang* product, each product packaged in the sample was found to be free from mechanical damage. The next step is to carry out retention controls on product samples and packaging.

3.2 Retention Control Time

According to Du et al. (2019), using kiwi fruit test samples as drop testing samples in their research, the samples were left in the laboratory at 25 °C for 24 hours after drop testing and then sliced. Kiwi fruit itself has a shelf life of 7 days if left open without using certain handling materials. Furthermore, on other fruit samples, apples have a relatively short shelf life, especially at room temperature, because apples, after being picked, undergo changes in composition, and damage occurs due to continued physiological activities (Isyuniarto and Purwadi, 2007). Since there is no previous literature regarding the retention time of *Jenang* samples, the researchers established a direct comparison relationship to determine the retention time of *Jenang* products. Based on the two studies above, the relationship between drop testing sample retention time and product shelf life is approximately 1:7. The *Jenang* product itself has a shelf life of roughly 75 days or around 2.5 months. Therefore, it can be determined that the retention time for *Jenang* products is 10 to 11 days, including drop testing and forensic packaging testing days.

3.3 Forensic Packaging Analysis

After a retention time of 10 to 11 days, the packaging samples and *Jenang* products are continued to the next stage, namely forensic packaging. On the last day of observation, it was found that the relative air humidity value increased from 64% to 77%. The data is presented in graphical form, as shown in Figure 3.

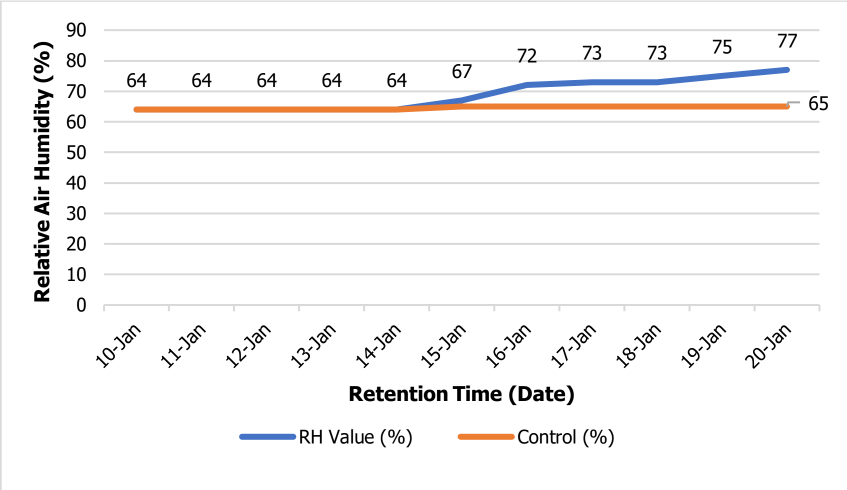


Figure 3. Chart of Samples Humidity Value During Retention Time

This increase in relative air humidity indicates a decrease in temperature in the sample compared to the beginning of the retention time. According to Edar and Wahyuni (2021), temperature affects the humidity value; if the room temperature falls, the relative humidity will rise, while if the temperature increases, the relative humidity will fall. During the retention time, the sample temperature is maintained at a range of 30 °C to 35 °C. This temperature range is the optimal temperature for activating lipoxygenase enzyme activity, which generally has an optimal temperature range of activation between 20°C and 40 °C. Activation of the lipoxygenase enzyme can also be triggered by mechanical damage to food products, exposing the enzyme to its substrate and thereby activating it. Then, exposure to oxygen can activate enzymes through the air, either during the production, storage, or handling processes. Furthermore, microbial contamination in food products can also affect the lipoxygenase enzyme, leading to the growth of fungi, mold, and algae in these products.

Based on observations, the *Jenang* did not appear bruised after undergoing the drop testing and retention time testing stages, and the product remained in intact condition. The condition is due to the characteristics of *Jenang* products, which have a chewy and elastic texture, making it difficult to identify bruises on the product and to slice it cleanly. Furthermore, the BOPP plastic packaging that packages *Jenang* products as a whole is still tightly packed, and some are slightly open. Therefore, the forensic packaging stage is carried out on packaging samples that have been identified as having bruises during drop testing. Based on the assessment indicators applied by the researchers, of the 9 packaging samples, there were 8 packaging samples in the "good" category and 1 packaging sample in the "very good" category, namely packaging 2.1, so in this sample, no part of the packaging was sliced because the damage to this sample was only small tear, not bruise. The determination of the cutting section is based on the part of the packaging with the highest percentage of damage and the deepest dents. Each package is sliced at the corners because it has the smallest number of parts (6 pieces) and the smallest contact surface area so the impact of the energy hitting the package will be greater due to the pressure being concentrated at one point. Based on Equations (7), (8), and (9), the summarized results of forensic packaging analysis are obtained, which are outlined in Table 5.

Table 5. Summarized Result of Forensic Packaging Analysis from Sample

Samples Code	Sliced Part from the Packaging	w1 (cm)	w1 (cm)	db (cm)	Bruise Area (cm^2)	Bruise Volume (cm^3)	Bruise Susceptibility (cm^3/Joule)
1.1	H Corner	0.600	0.400	0.040	0.189	0.023	0.054
2.1	Unsliced	Unsliced	Unsliced	Unsliced	Unsliced	Unsliced	Unsliced
3.1	E Corner	0.840	0.615	0.038	0.405	0.046	0.111
1.2	G Corner	0.800	0.600	0.043	0.368	0.049	0.057
2.2	A Corner	1.000	0.800	0.040	0.628	0.076	0.090
3.2	C Corner	0.780	0.720	0.048	0.441	0.064	0.073
1.3	E Corner	1.020	0.600	0.048	0.565	0.070	0.054
2.3	H Corner	1.050	0.710	0.043	0.585	0.076	0.062
3.3	E Corner	1.070	1.010	0.048	0.848	0.123	0.094

Therefore, the final results of the bruise susceptibility values and the inaccuracies in their calculation can be seen in the final results in Table 6.

Table 6. Final Result of Bruise Susceptibility Value and Its Standard Deviation

Height (cm)	Samples Code	Bruise Susceptibility (cm^3/Joule)	Average Bruise Susceptibility (cm^3/Joule)	Standard Deviation Value (cm^3/Joule)	Bruise Susceptibility ± Standard Deviation Value
50	1.1 2.1 3.1	0.054 - 0.111	0.055	(**n.a**)	**0.0549 cm^3/J**
100	1.2 2.2 3.2	0.057 0.090 0.073	0.073	0.016	**0.0735 ± 0.0164 cm^3/J**
150	1.3 2.3 3.3	0.054 0.062 0.094	0.070	0.021	**0.0699 ± 0.0214 cm^3/J**

Furthermore, the data on bruise susceptibility value is presented in a scatter plot chart type to analyze the trend due to the increase in drop fall height and the value of bruise susceptibility for sample packaging. Based on the graphic shown Figure 4, there is a positive trend between height fall and bruise susceptibility, with a coefficient of 0.0004. Therefore, a change in height of 1 unit cm can affect the bruise susceptibility value by 0.0004 cm^3/J. Additionally, the R-squared value is 99.9%, indicating that the fall height accounts for 99.9% of the variation in bruise susceptibility values. The square root value of R-squared is also referred to as the correlation coefficient (r), so the value of the r coefficient is 0.999. The value indicates a very strong positive correlation. The graph is shown in Figure 4.

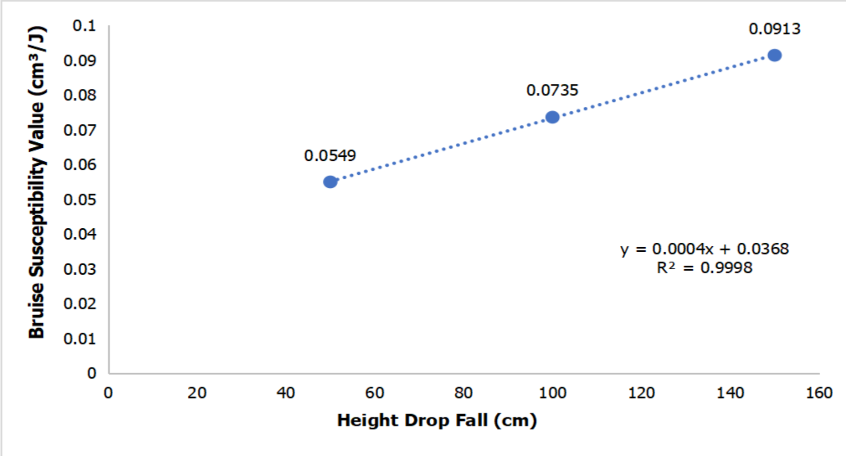


Figure 4. Scatter Plot Diagram: Height Drop Fall and Bruise Susceptibility Value

Figure 4 shows an upward trend in data, resulting from the average bruise susceptibility and its standard deviation from 3 repetitions at drop heights of 50 cm, 100 cm, and 150 cm. At the first height fall (50 cm), the value of bruise susceptibility was approximately 0.0549 cm^3/J. Then, on the second height fall (100 cm), the value of bruise susceptibility obtained was approximately 0.0735 cm^3/J. For the third height fall (150 cm), the value of bruise susceptibility obtained was approximately 0.0913 cm^3/J. The third height fall sample has the highest value of bruise susceptibility among the others due to its bruise size being affected by more damage (length, width, and depth) than the first and second height fall samples.

Based on the graph shown Figure 4, the relationship between increasing the falling height used and the level of damage experienced by the packaging is directly proportional. The relationship means that the higher the fall, the more severe the damage to the packaging, which in turn will affect the product.

4. CONCLUSIONS

Based on the research conducted by the researcher, it can be concluded to some extent that there is an indirect influence of mechanical defects on *Jenang's* quality degradation. Changes in *Jenang's* characteristics are caused by the activity of the lipoxygenase enzyme in the product due to various substrates, including a decrease in temperature, an increase in relative humidity (RH), excessive water activity, air (O_2 gas content), and microbial contamination. Then, the packaging used by the company is supplied by PT. Bima Perkasa Semarang is already in the "good" category. Proven by three times repetitions of testing at each of three heights (50 cm, 100cm, 150cm), the bruise susceptibility value is very low, packaging damage is in the light category, and the product's primary packaging is still tightly sealed, so that it can maintain the quality and shelf life of *Jenang* during the retention period. Furthermore, the average values and their deviations for bruise susceptibility of the packaging at heights of 50 cm, 100 cm, and 150 cm, respectively, were 0.0549 cm^3/Joule, 0.0735 ± 0.0164 cm^3/Joule, and 0.0699 ± 0.0214 cm^3/Joule.

The packaging standard itself is made from the result of this test specification because the secondary flip carton packaging from a third-party company, which was tested in this study, has been categorized as "good to very good" indicators based on the test method carried out so that it can be used as a standard and reference for the carton packaging used. The creation of its standard can be used as historical company data because no standards have been applied regarding secondary packaging parameters. If there are any new alternative packaging options from other suppliers, the testing selection methods must be carried out using the same test method. Also, the quality of the new packaging to avoid deformation (resistance) should be better than the previous packaging vulnerability value applied to the standard. Therefore, it is hoped that this research will help companies adapt and evaluate better material handling practices, determine standard packaging attributes and parameters based on test results data, and provide information on the packaging's ability to protect *Jenang* products, along with damage simulations and forensic evidence.

Based on the research, the researcher can provide suggestions to ensure the research is utilized effectively. The first factor for selecting new packaging alternatives from other suppliers is not limited to mechanical durability alone but also considers price, design, and other factors. Furthermore, there are various techniques for decision-making analysis, such as the analytical hierarchy process (AHP), analytical network process (ANP), and the TOPSIS method, among others, to determine priority factors from attributes.

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Analysis of MSMEs' Cassava Production Efficiency Using a Comparison of Machine Learning Models in Jember Regency

Danang Kumara Hadi*[1,2] and Yuta Sato[2]
[1]Department of Agroindustrial Technology, Faculty of Agriculture
Universitas Muhammadiyah Jember, Jl. Karimata No. 49, Jember 68124, Indonesia.
[2]Graduate School of Engineering, Ibaraki University, Japan
Email: danangkumara@unmuhjember.ac.id*

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Abstract
Cassava is one of Indonesia's agro-industrial commodities, but many Micro, Small, and Medium Enterprises (MSMEs) in the cassava processing industry face difficulties in achieving optimal production efficiency. This study aims to evaluate the efficiency of cassava processing production systems in MSMEs in Jember by comparing machine learning algorithms (Linear Regression, Random Forest, Support Vector Regression (SVR), and XGBoost) to predict output and key efficiency factors. The data used consists of 250 data points: 80% for model training and 20% for testing to build a machine learning-based prediction model, with input features production processing as the X-axis, and output in the form of production volume as the Y-axis. Data preprocessing, exploratory data analysis, and modeling were conducted using Python, with evaluation based on MAE, RMSE, and R^2 metrics. Among the tested models, Random Forest demonstrated the best performance with an R^2 value of 0.990. Sensitivity analysis revealed that production output increases significantly with the addition of labor and machines, with an optimal configuration of 15–20 workers and 2–3 machines per batch. The study concludes that focusing on overall production efficiency rather than merely increasing resources is the most effective strategy.

Keywords: *Cassava, Efficiency Analysis, Machine Learning Algorithm, Prediction Model.*

1. INTRODUCTION

Cassava (*Manihot esculenta*) is one of the strategic food commodities in Indonesia that has high economic value and great potential as an agro-industrial raw material, such as the tapioca flour industry (Aminanti Suraya Putri et al., 2020), modified starch (Hamidi and Banowati, 2019), bioethanol (Shanavas et al., 2011), and snacks or chips (Hadi et al., 2021). Jember regency has the advantage of cassava commodity which lies in its high productivity, tolerance to marginal land, as well as a relatively fast planting cycle and suitable soil for planting (BPS kabupaten jember, 2020). However, in practice, cassava micro, small and medium enterprises (MSMEs) in Jember Regency often face challenges in achieving optimal production efficiency.

The efficiency of the production system is strongly influenced by many factors, such as the number of workers (Sosa-Perez et al., 2020), machine capacity (Niekurzak et al., 2023), process time (Rosova et al., 2022) at each stage of production (washing, peeling, drying), to the work system per shift. Inefficiency in the management of the production process can lead to decreased productivity, waste of resources, and high operational costs (Kumara et al., 2023). Therefore, an analytical approach is needed to understand the dynamics of the production system and identify crucial points that affect efficiency (Hadi et al., 2023).

Along with the development of data technology in the era of artificial intelligence (AI), machine learning (ML) based approaches have become one of the effective methods in predicting, classifying, and optimizing industrial systems (Kreuzberger et al., 2023; Yan, 2022; Zhang et al., 2022). ML is able to model complex relationships between various production variables and provide accurate predictions of output or work efficiency. Another advantage is ML's ability to learn patterns

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from historical data and recommend data-driven decision making strategies for system improvement (Kumar et al., 2020; Moosavi et al., 2020; Zaki et al., 2020). However, the application of machine learning in small and medium scale agro-industries (Benos et al., 2021; Elbasi et al., 2023), especially in the context of cassava production, is still very limited. Many industry players do not have a systematic approach in measuring and improving their production efficiency. In fact, with the right approach, this technology can provide strategic recommendations based on actual and historical data simulations (D'Amour et al., 2022).

This research was conducted to examine how the performance of the cassava production system is viewed from actual process data, identify the factors that have the most influence on production efficiency, and determine the most accurate machine learning algorithm in predicting output or work efficiency at XYZ MSME. The main objective of this research is to build a Python-based predictive model using several algorithms such as Linear Regression, Random Forest, Support Vector Regression (SVR), and XGBoost, and evaluate the performance of each model based on standard metrics (Subasi, 2020). The results of this research are expected to make a real contribution to the development of production efficiency strategies in the cassava agro-industry sector, especially for small and medium scale industry players who want to apply data-based analytical approaches in a practical and measurable manner. This comparative analysis also shows that Random Forest excels in handling non-linear data and has good feature interpretability, but requires more computational resources than Linear Regression. Thus, this research not only provides a predictive model, but also provides practical considerations regarding algorithm selection based on data complexity and user requirements. Until now, there has been no research that directly compares the performance of several machine learning algorithms in the context of output prediction and production efficiency in the cassava processing industry in Jember. Therefore, this research makes a new contribution with an ML model comparison approach that is applicable and specific to local agroindustry conditions.

2. MATERIAL AND METHODS

2.1 Data Collection

Data is collected from the actual production process and the results of simulations that have been carried out previously at XYZ MSME. The dataset used amounted to 250 observation data. List the input features including the number of workers, number of machines, number of shifts, washing time, peeling, drying, total production time, and process efficiency as the X-axis and output in the form of production quantities as the Y-axis. The resulting dataset contains a number of important variables that represent operational conditions and process performance, such as the number of workers, the number of machines used, the number of work shifts, the time required at each stage of the process, the total production time, the amount of output produced, and the overall level of process efficiency. The research scheme is presented in Figure 1.

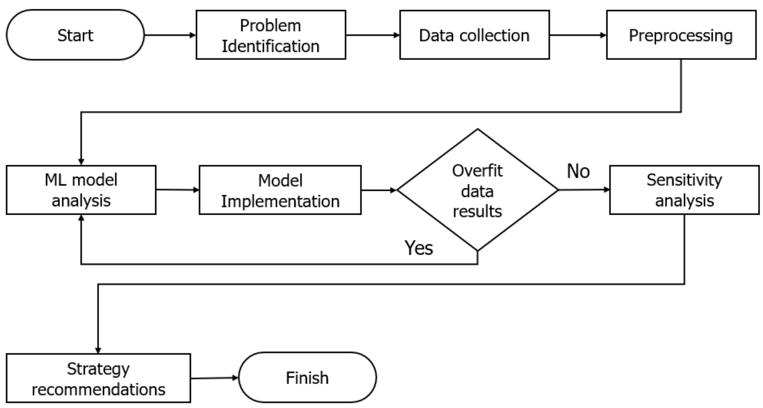


Figure 1. Research scheme of efficiency analysis in cassava processed product production system using Machine Learning Algorithms

The dataset is then randomly divided into two parts: 80% as training set and 20% as testing set. This division aims to allow the model to learn patterns from historical data and be tested using previous data. The training data is used to train the machine learning model to understand the pattern of the production process, while the testing data is used to test the performance of the model against new data that has never been seen before. This separation is important so that the model can produce accurate predictions and not experience overfitting.

2.2 Preprocessing & Exploratory Data Analysis (EDA)

It is important to prepare and understand the data before modeling. Using Pandas, NumPy, Matplotlib, and Seaborn, the data is analyzed through feature scaling, value distribution, correlation between variables, and outlier identification. The goal is to ensure the data is ready and relevant for the model training process (Subasi, 2020). The selection of machine learning algorithms in this study is based on data characteristics and prediction needs. Linear Regression was chosen as the basic model that is easy to interpret. Random Forest was chosen for its ability to handle non-linear data and robust to outliers. SVR was chosen for its ability to work well on high-dimensional data and limited sample size. XGBoost was chosen for its efficiency in boosting and its ability to produce high accuracy on complex data. This diverse approach allows a thorough evaluation of model performance based on the context of cassava production data (Kreuzberger et al., 2023; Kumar et al., 2020; Subasi, 2020).

2.2.1 Linear Regression

Linear Regression is used to model the linear relationship between input (feature) and output (target) variables (Manurung et al., 2024). General formula:

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon \quad (1)$$

Where:

$\hat{y}$: predicted output
x_i : i-th feature
β_i : regression coefficient
ε : error/residuals

2.2.2 Random Forest Regressor

Random Forest is a bagging-based ensemble algorithm that uses many decision trees to generate average predictions (Erkamim et al., 2023).

$$\hat{y} = \frac{1}{T}\sum_{t=1}^{T} h_t(x) \quad (2)$$

Where:

T : number of trees
$h_t(x)$: prediction of the t tree
$\hat{y}$: average prediction of all trees

2.2.3 Support Vector Regression (SVR)

SVR seeks a regression function that has a minimum margin of error ε and is tolerant of small deviations (Sepri and Fauzi, 2020).

$$min\frac{1}{2}\|w\|^2 \text{ subject to: } \left|y_i - (w.x_i + b)\right| \le \varepsilon \quad (3)$$

Where:

w : weight vector
b : bias/intercept
ε : error tolerance

2.2.4 XGBoost Regressor

XGBoost is a boosting algorithm that builds the model incrementally, by adding new trees that focus on correcting the errors of the previous trees (Syafei and Efrilianda, 2023).

$$\mathcal{L}(\phi) = \sum_{i=1}^{n} l(y_i, \hat{y}_i) + \sum_{k=1}^{K} \Omega(f_k) \tag{4}$$

Where

$$\Omega(f) = \gamma T + \frac{1}{2}\lambda \|w\|^2 \tag{5}$$

Where:

l : loss function (e.g. RMSE)
$\Omega(f)$: regularization to avoid overfitting
T : number of leaves in the decision tree
λ, γ : regularization parameters

2.2.5 Cross-Validation dan Hyperparameter Tuning k-Fold Cross-Validation

Cross-validation is used to ensure the model does not overfit or underfit. The data is divided into k parts. Each part becomes the test set once and the training set k-1 times (Kusunartutik and Dwidayati, 2022).

$$Score = \frac{1}{k}\sum_{i=1}^{k} Metric \tag{6}$$

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis of Data

The analysis is carried out in stages, starting from data exploration, predictive model building, model performance evaluation, to interpretation of prediction results and sensitivity analysis of important variables (Bhargav et al., 2024). Each stage is discussed in detail to illustrate the accuracy of the model as well as the relevance of the results to the actual production system being analyzed.

Descriptive statistics are presented in Figure 2 to provide an overview of the distribution of data obtained from the production system in cassava processing MSMEs. This visualization includes key variables such as washing, peeling, drying, total process time, total output, and production efficiency. Each boxplot displays the minimum, median, and maximum values, as well as the possibility of outliers, thus helping to understand the characteristics and stability of the production process in the field. From the image data, data transformation using scaling and data normalization is divided into 80% for training and 20% for testing. Figure 3 shows the support data of human resources and machinery on production execution.

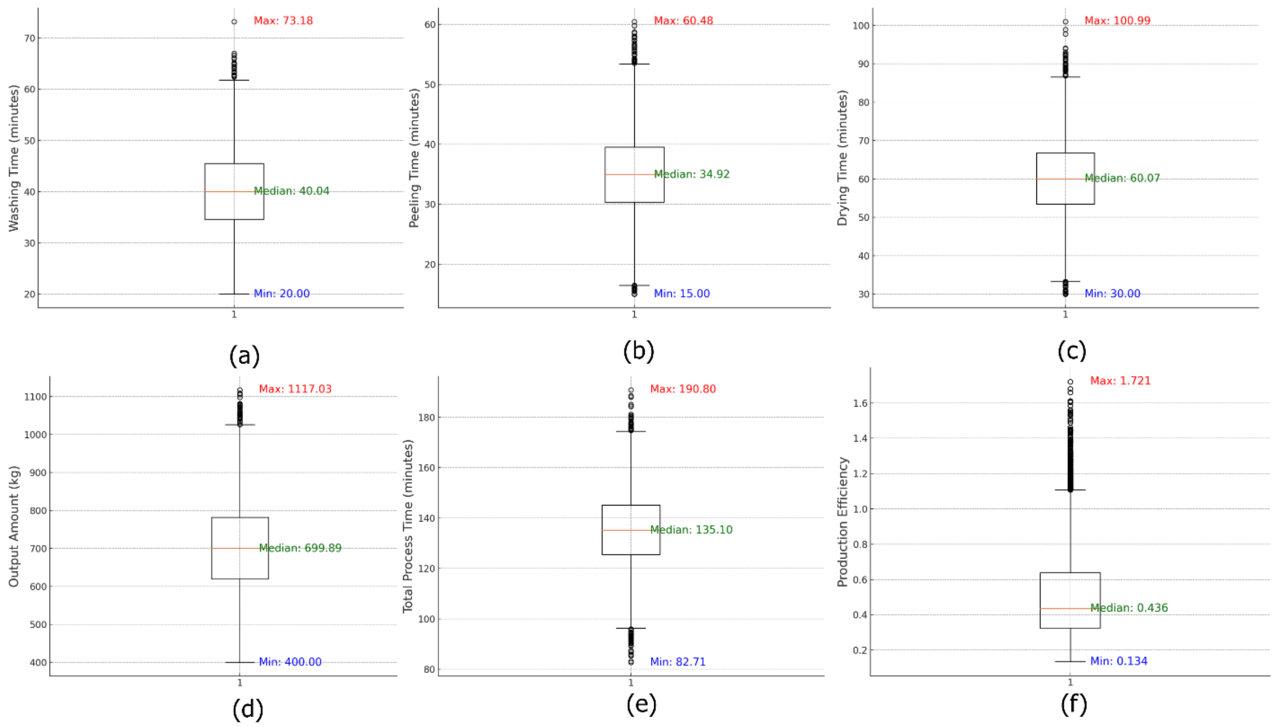


Figure 2. Box-and-whisker plot overview of the distribution of data obtained from the production system in cassava processing MSMEs (a) Washing Time (b) Peeling Time (c) Drying Time (d) Output Amount (e) Total Process Time (f) Production Efficiency

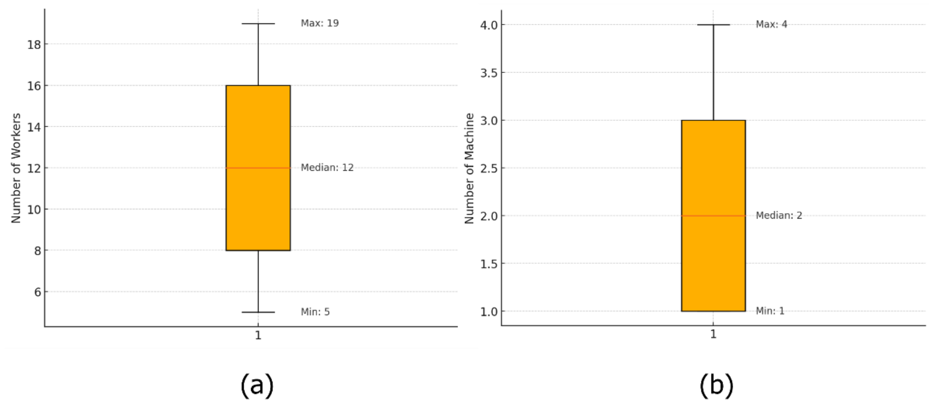


Figure 3. Supporting data for production implementation each batch (a) Number of workers data (b) Number of machine data

3.2 Modeling Implementation Results

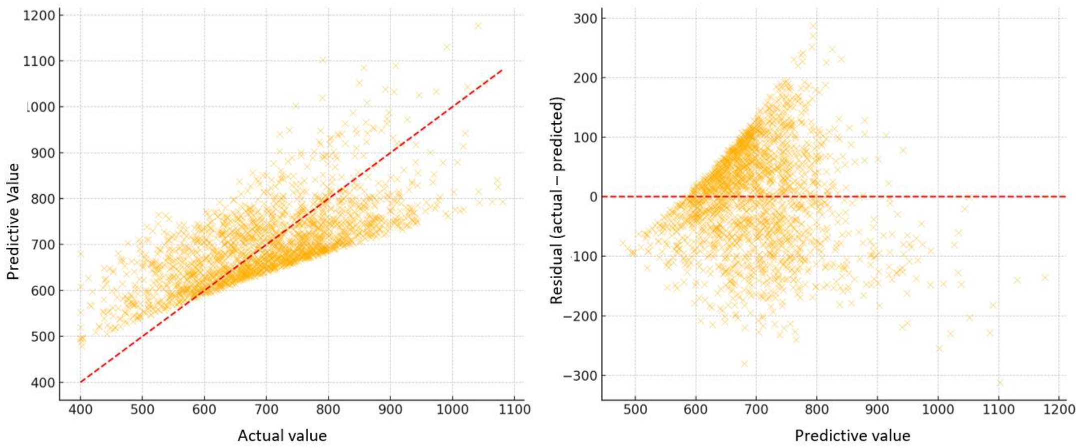
Model evaluation and interpretation were conducted to measure the performance of the machine learning algorithms used in predicting cassava production output. Evaluation is carried out using three main metrics, namely Mean Absolute Error (MAE) to determine the average absolute error, Root Mean Square Error (RMSE) to measure the deviation of predictions from actual values, and R^2 Score to see the extent to which the model is able to explain variations in output data. The comparison metric research results of the data obtained are presented in Table 1.

Table 1. Metric of model comparison of data

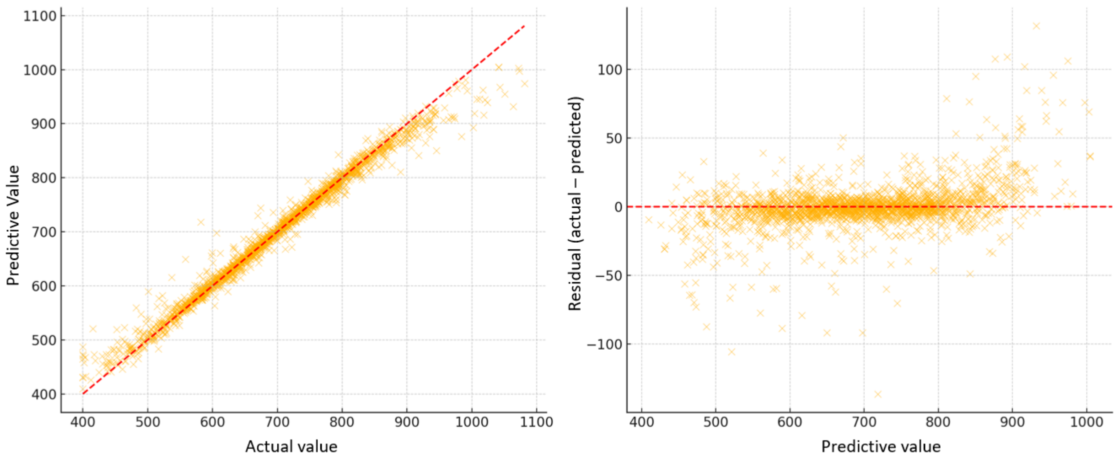
Model	MAE	RMSE	R^2 Score
Linear Regression	69.52	85.97	0.48
Random Forest Regressor	9.54	16.84	0.99
Support Vector Regression (SVR)	5.30	11.74	0.98
XGBoost	24.14	33.38	0.92

Based on the very high R^2 value of 0.990 (close to 1), the Random Forest model is proven to be able to explain almost all variations in cassava production output data. This value makes Random Forest one of the best models in this study, especially when considering the balance between predictive accuracy, stability, and interpretation. In addition to the very high R^2 value (0.99) which shows that the Random Forest model is able to explain almost all variations in the production output data, the MAE and RMSE values also support the accuracy of this model. The MAE of 9.55 indicates that the average prediction error of the model is only about 9.55 output units, while the RMSE of 16.84 indicates a relatively low level of deviation of predictions from actual values. When compared to other models, Random Forest provides the best balance between prediction accuracy and model stability, outperforming SVR (MAE = 5.31; RMSE = 11.75 but with higher computational cost) and Linear Regression (MAE and RMSE are much larger, indicating the model's mismatch with the data pattern).

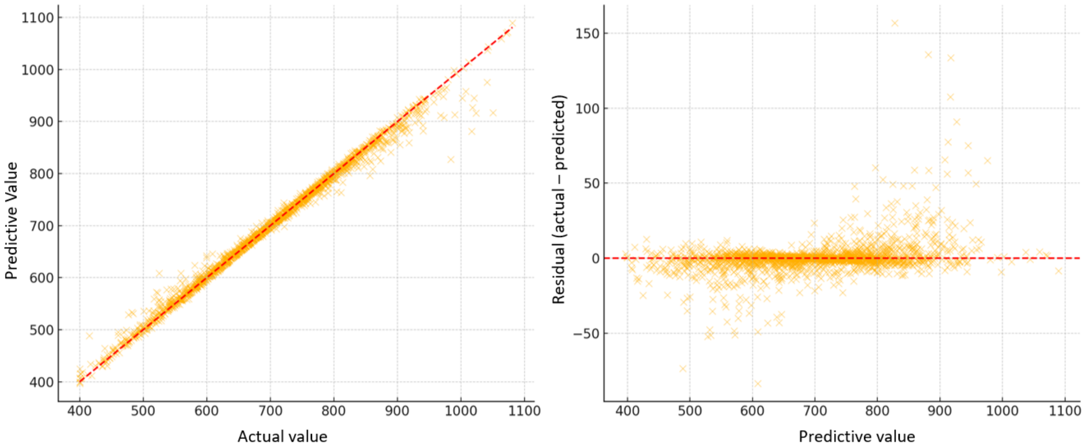
In addition, the model predictions were compared with the actual data through scatter plot and residual plot visualizations to identify the accuracy and error patterns of the model presented in Figure 4. Model interpretation is complemented by feature importance analysis to identify the input factors that have the most influence on the amount of output, so that they can be used as a basis for decision-making and production optimization strategies.



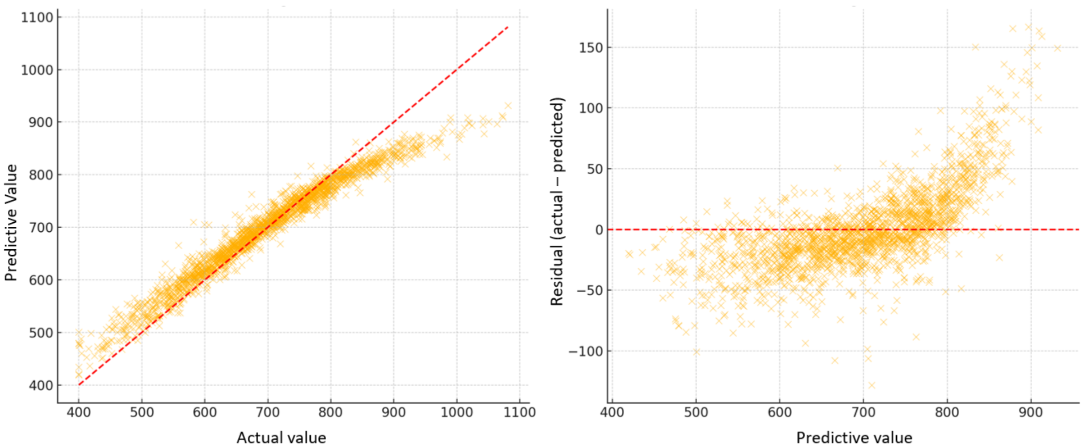
(a)



(b)



(c)



(d)

Figure 4. Scatter plot and residual plot visualizations to identify the accuracy and error patterns of the model, the left picture shows the regression between prediction and actual, the right picture shows the residual plot (a) Linear regression (b) Random Forest (c) SVR (d) XGBoost.

Feature importance is based on the results of model interpretation based on the Random Forest Regressor algorithm, which is excellent for measuring the relative influence of each feature as well as the correlation to production output. The implementation of the feature importance model and correlation analysis with production output/efficiency is presented in the heatmap in Figure 5. From the data in Figure 5, to increase cassava production output, MSMEs should focus on improving overall production efficiency rather than just increasing the number of workers or speeding up process time.

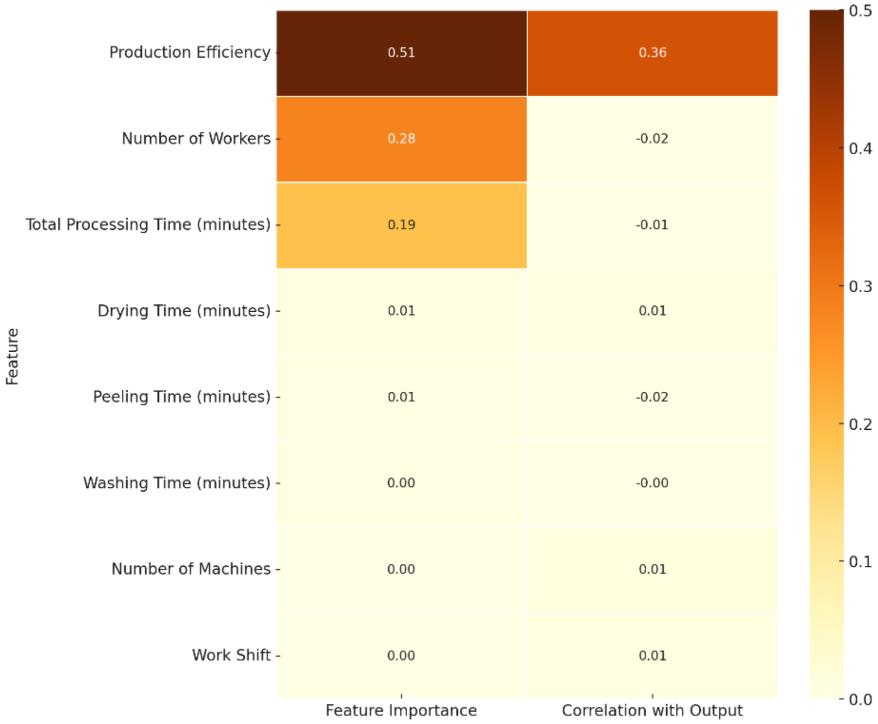


Figure 5. Heatmap of feature importance model and correlation analysis with production output/efficiency

3.3 Sensitivity Analysis

Sensitivity analysis was conducted based on the results of scenario simulation tests based on the Random Forest Regression model. The analysis was conducted by modifying the labor variables and the number of machines. Other scenarios (shift, processing time, etc.) were assumed to be constant at the average value. The results of the sensitivity analysis are presented in Figure 6. From the results, an increase in the number of workers significantly increases production output, an increase in the number of machines also has an effect, although not as great as labor. The combination of optimal labor and sufficient number of machines yields the best output prediction.

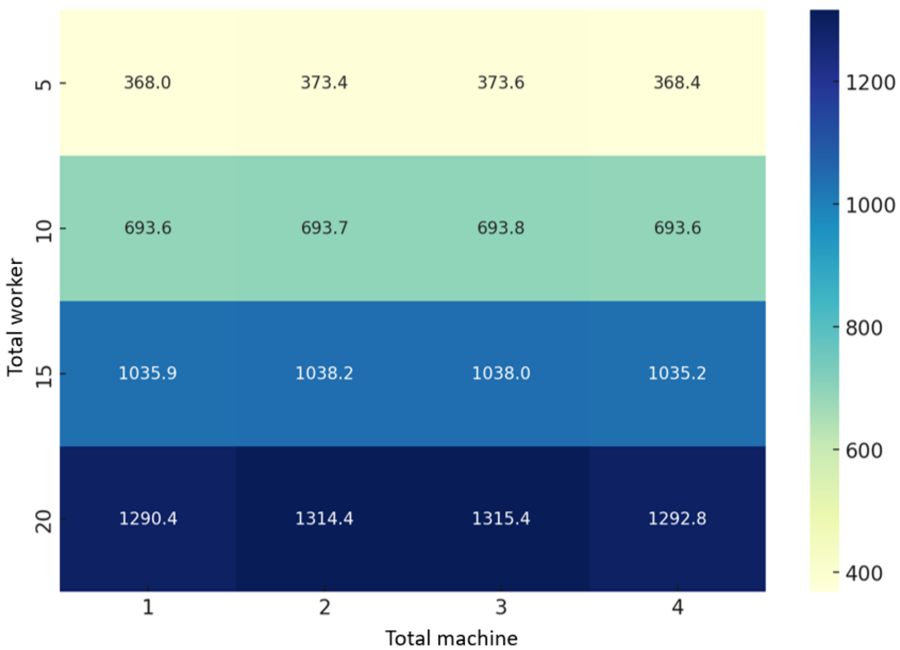


Figure 6. The heatmap results of the sensitivity analysis

Based on the results of the study, the recommended optimal strategy to increase output and efficiency of cassava production is to focus efforts on improving overall production efficiency through more measurable management of labor, process flow, and working time. The optimal number of workers is in the range of 15-20 people per batch, supported by 2-3 units of machinery for maximum results without wasting resources. The application of machine learning-based prediction models, especially Random Forest Regression, can be an accurate tool in operational decision-making. In addition, companies are advised to start implementing simple monitoring systems and data-driven approaches to create a more adaptive, efficient, and sustainable production process.

As a complement to the sensitivity analysis, a simple ANOVA test was conducted on the simulated output results based on variations in the number of workers and machines. The results show that the variation in the number of workers has a statistically significant effect on production output ($p < 0.05$), while the effect of the number of machines is significant only to a certain degree. This suggests that strategic decisions in labor allocation have more impact on increasing output than adding machines, in the context of the existing system.

3.4 Critical Discussion

The implication of this study is the need for a more widespread data-driven approach among MSMEs to support operational decision-making and efficiency. Based on the results of feature importance analysis in the Random Forest model, the features that have the most influence on production output are the number of workers, number of machines, and total processing time. This is consistent with the theory of production in cassava MSMEs, where labor and machine capacity are the main drivers of productivity.

Model evaluation showed that the Random Forest model had an R^2 of 0.990, while the Linear Regression model only reached 0.48. This very high R^2 value can lead to indications of overfitting, but the results of the cross-validation test (5-Fold CV) show that the difference in performance between training data and test data is relatively small, which indicates that the model does not experience significant overfitting. Linear models also tend to be underfitting because they are unable to capture the complexity of relationships between variables.

When compared to the research of Nur et al., 2023, the Random Forest and XGBoost approaches also show high performance in predicting agricultural yields, but this study emphasizes more on simulating combinations of operational variables for sensitivity analysis, which has not been done specifically in the cassava processing MSME sector.

Although the model has high accuracy, there are several limitations, including simulative and historical data from one MSME, so generalization to other industries or regions is still limited. Some important variables such as raw material quality and weather are not included, which could have an impact on prediction accuracy. The model does not test cost efficiency, focusing only on physical output.

4. CONCLUSIONS

Applying several machine learning algorithms, this research successfully built a prediction model for cassava production output with a very high level of accuracy. The Random Forest Regression model showed the best performance with an R^2 value of 0.990, outperforming SVR, Linear Regression, and XGBoost.

Through sensitivity tests and scenario simulations, it was found that the optimal combination of labor (15-20 people) and number of machines (2-3 units) gave the highest predicted output. The addition of work shift variables does not have a significant impact without good efficiency management. Therefore, the recommended approach is to prioritize overall efficiency, not just the addition of resources. By utilizing machine learning as a prediction and decision-making tool, cassava agro-industry companies can optimize resources, increase productivity, and move towards a smarter, data-driven production system.

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Coffee Supply Chain Performance Measurement in Ulu Belu District, Tanggamus Regency, Lampung Province

Teny Sylvia*[1], Teguh Wiyono[1], Endo Pebri Dani Putra[1], Muhammad Asrol[2], Noveliska Br Sembiring[1], Eka Nur'azmi Yunira[1], Deni Subara[1], Wilda Harlia Devita[1]

[1]Department of Agricultural Industrial Technology, Faculty of Industrial Technology, Sumatera Institute of Technology, Terusan Rya Cudu St., Way Hui, Jati Agung, South of Lampung, Indonesia
[2]Department of Industrial Engineering, Binus University, K. H. Syahdan St., No. 9, Kemanggisan, Palmerah Jakarta, Indonesia
Email: teny.sylvia@tip.itera.ac.id*

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Abstract

Ulu Belu District, as the largest producer of robusta coffee in Lampung Province, faces challenges throughout its coffee supply chain, from cultivation to marketing. This study aims to examine the structure of the coffee supply chain, evaluate its performance using the Supply Chain Operations Reference (SCOR) model combined with the Analytic Network Process (ANP), and recommend strategies for improvement. The identification results reveal that the coffee supply chain in Ulu Belu District involves several key actors, including farmers, commodity aggregators, collectors, business partners, ground coffee processors, domestic roasters, retailers, exporters, and consumers. This supply chain operates through the flow of products, information, and financial resources among these actors. The coffee supply chain performance measurement results in Ulu Belu District indicate a very poor overall performance score of 58.855. Performance at the three supply chain tiers also reflects concerning conditions: farmers scored 59.721, indicating a very poor performance; collectors scored 62.888, reflecting a poor condition; and business partnerships scored the lowest at 53.957, also categorized as very poor. The strategies for improving supply chain performance include providing training and outreach on Good Agricultural Practices (GAP), implementation of GAP and Good Handling Practices (GHP), implementation of the Common Code for the Coffee Community (4C) certification, increasing storage warehouse capacity, implementing Collaborative Planning, Forecasting, and Replenishment (CPFR) in supply chain management in Ulu Belu, determining safety stock, and planning delivery schedules.

Keywords: *ANP, Coffee, Performance Measurement, SCOR, Supply Chain.*

1. INTRODUCTION

Indonesia is the fourth largest coffee producer and exporter after Brazil, Vietnam, and Colombia (USDA, 2025). The total coffee production in Indonesia in 2024 was 654,000 tons. Lampung is the second largest producer of robusta coffee in Indonesia, with a total production of 108,069 tons in 2024 (Ditjenbun, 2024). The central areas of coffee development in Lampung Province are located in West Lampung and Tanggamus Regencies. In 2022, Robusta coffee production in Lampung reached 113,739 tons, primarily sourced from smallholder farmers (Directorate General of Estates, 2023). Tanggamus Regency is among the leading coffee-producing areas in Lampung Province. The area of Tanggamus Regency is 285,546.00 Ha, which contains a plantation area of 85,924.65 Ha. The plantation area has a share of 35% of the area of Tanggamus Regency (BPS Tanggamus Regency, 2020). Ulu Belu is a district in Tanggamus Regency that has the highest coffee production in Lampung Province. With a coffee production volume of 10,388 tons, Ulu Belu District stands out as one of the leading coffee producing areas in Lampung Province. While this figure is higher than that of many other areas in Lampung Province, it also reflects the region's significant role in national coffee output. However, various issues across the supply chain from upstream (cultivation and harvesting) to downstream (processing and marketing) indicate that there

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is still considerable room for improvement. Addressing these bottlenecks presents an opportunity for Ulu Belu to further increase its coffee production and enhance its contribution to Indonesia’s foreign exchange through coffee exports.The problem in the downstream part of the coffee supply chain, such as in small industries, is having limited processing machines, which hinders the efficient processing of coffee beans, and a lack of innovation in creating diversification of processed coffee products. The low innovation is caused by farmers being accustomed to selling in the form of green beans (Darwis et al., 2020).

Product diversification and value addition are vital in improving supply chain performance, particularly in small-scale coffee industries. These businesses can move beyond merely selling raw coffee beans by innovating and developing new coffee-based products—such as ready-to-drink beverages, or cosmetic items. This shift allows them to capture more value at the processing and marketing stages. As a result, they can increase their revenue streams, reduce dependence on selling green beans, and gain access to a broader range of markets. This strengthens their competitive position and makes the supply chain more robust and sustainable in the long term. This shift contributes to efficiency by optimizing the use of raw materials, enhances agility by enabling businesses to respond quickly to changing consumer preferences, and promotes sustainability by supporting long-term economic viability and reducing overreliance on a single product type.

According to Shekarian et al. (2022), supply chain management is an integrated strategy for overseeing the movement of products, data, and financial resources throughout the whole supply chain from initial suppliers of raw materials to final consumers to enhance efficiency, agility, and sustainability. The system in the supply chain can run smoothly if there is certainty in the number of suppliers of raw materials and certainty the amount of demand. Measuring supply chain performance is important because of the large number of coffee supply chain actors involved. The results of measuring supply chain performance can be used as evaluation material to see the current performance position. In addition, the results of these measurements can be used as a basis for developing strategies to improve supply chain performance (Asrol et al., 2017).

In this study, the robusta coffee supply chain in Ulu Belu District is assessed using a combination of the Supply Chain Operations Reference (SCOR) model and the Analytic Network Process (ANP) method. The SCOR model is employed because it provides a standardized framework for evaluating supply chain performance through five key attributes: reliability, responsiveness, agility, cost, and asset management. It enables organizations to understand, measure, and systematically improve their supply chain processes by aligning them with best practices and benchmarks. Meanwhile, the ANP method is chosen for its ability to handle complex, interdependent decision-making environments. Unlike traditional linear models, ANP accommodates feedback and interrelationships among elements making it suitable for evaluating the multi-criteria nature of supply chain performance. It allows for prioritizing key performance indicators (KPIs) by considering expert judgment and the interdependence of SCOR attributes. Combining SCOR and ANP offers a comprehensive and robust approach: SCOR provides the structural basis for identifying performance dimensions, while ANP enhances decision-making by determining the relative importance of each performance indicator. Through this integrated approach, the study aims to generate meaningful insights for robusta coffee supply chain actors in Ulu Belu, helping them identify current performance and determine strategic improvements. The specific objectives of the study are to examine the structure of the robusta coffee supply chain, analyze its performance using SCOR and ANP, and provide targeted recommendations to enhance its efficiency, sustainability, and competitiveness.

2. MATERIAL AND METHODS

Data were collected in Ulu Belu District, Tanggamus Regency, Lampung Province. The location of this study was chosen purposively because Ulu Belu District has the highest coffee production of all districts in Lampung Province. This research was carried out with the initial stages being a preliminary survey and literature study conducted to understand and find out the condition of the coffee supply chain so that the research runs well and correctly. Furthermore, the problem can be identified by conducting direct observations in Ulu Belu District. The issues that have been identified are then formulated, and the research objectives are determined. The second stage is the collection of primary and secondary data. Primary data was collected using purposive and snowball sampling for all coffee supply chain actors in the Ulu Belu district. Furthermore, the coffee supply chain can be identified by describing the problems of supply chain performance using the direct interview method with experts.

In this study, supply chain modeling will be carried out to determine the actors involved in the coffee supply chain in Ulu Belu District. In addition, supply chain modeling can help describe the existing coffee supply chain conditions. In the initial performance measurement stage, Key Perfomance Indicator (KPI) determination is carried out based on 5 core processes: plan, source, make, deliver, return in SCOR version 12.0. The selection of the SCOR version 12 Level 3 model in assessing coffee supply chain performance is based on several strategic and contextual considerations. SCOR 12 is still a relevant standard and is widely used in traditional agribusiness industries such as coffee because this model focuses on basic logistics processes such as planning (Plan), procurement (Source), production (Make), shipping (Deliver), and returns (Return). Level 3 of this model provides the operational details needed to measure activities more granularly, from harvesting and processing to distributing coffee to end consumers. In addition, SCOR 12 has been widely tested and supported by various literature and previous case studies, making it easier to compare (benchmark) and validate the analysis results. Meanwhile, the another version, such as the SCOR Digital Standard (version 13), is more oriented towards digital transformation and automation of industrial processes, which in practice have not been fully implemented in the coffee supply chain, which tends to be traditional and labor-intensive (Özkanlısoy et al., 2023). Therefore, SCOR 12 Level 3 is more appropriate and applicable for this context.

Then, it is continued by creating a KPI network model to determine the clusters and nodes identified and describe the network model. The instruments used in this study were KPI validity questionnaires, KPI weighting questionnaires, and performance assessment questionnaires. This questionnaire was validated through face validity and was assessed by 5 (five) selected experts, consisting of 2 (two) field agricultural extension officers, 1 (one) lecturer from a supply chain management expertise group, and 2 (two) experienced coffee farmers from the Ulu Belu District. These experts were selected based on their qualifications and relevant experience in coffee agroindustry and supply chain. The agricultural extension officers were chosen for their active role in providing technical assistance and field-level support to coffee farmers in Ulu Belu for more than 5 (five) years. The lecturer was selected based on their academic background and research experience in supply chain management, particularly within agroindustry. The coffee farmer experts were chosen due to their long-standing involvement in coffee cultivation, processing, and marketing, with at least 10 (ten) years of practical experience. They recognized leadership roles in local farmer groups. Their collective insights were considered valuable in evaluating the content validity and relevance of the questionnaire items to ensure alignment with real-world practices in the coffee supply chain. Futhermore to ensure the validity of the SCOR (Supply Chain Operations Reference) scores used as key performance indicators (KPIs), it is essential to consider the qualifications of the respondents, as their assessments significantly influence the overall analysis. Therefore, respondent selection was based on clearly defined criteria. In this study, coffee farmers, as the initial sampling point, were required to meet the following criteria: coffee farming must be their primary occupation, and they must own a minimum of 1 hectare of land. Collectors and members of Coffee Farmer Groups (KUB) were selected based on their involvement in the coffee business for at least five years and their knowledge and skills in coffee cultivation, processing, and marketing within the Ulu Belu District.

The weighting of the coffee supply chain KPI was carried out using the ANP method. The results of the weighting of the inter-cluster relationships are arranged in a cluster metric. The weighting is continued on the inter-node relationships arranged in the appropriate metric cells. The supermatrix obtained is unweighted, so weighting is needed to obtain a weighted supermatrix. The way to get the weighted supermatrix is calculated by multiplying the value of the cluster matrix cell by the value of each unweighted supermatrix cell.

The next stage in processing performance data is normalization, which aims to standardize the scale of the KPI value. Each KPI has a different scale of measurement, so equalizing the parameters by normalizing using the Snorm de Boer equation is necessary. The values obtained from the performance measurement results are categorized based on different scales. Therefore, data normalization is required to calculate overall performance and facilitate the measurement of each metric. Normalization can be carried out using the Snorm de Boer formula as seen in Formula 1 and 2.The final value will be calculated by multiplying the normalization result by the ANP weight of each work indicator. The multiplication results are added up to obtain the total value.

a. Snorm de Boer Normalization (Larger is Better)

$$\text{Snorm} = \frac{(Si - Smin)}{(Smax - Smin)} \text{ x100} \tag{1}$$

b. Snorm de Boer Normalization (Lower is Better)

$$\text{Snorm} = \frac{(Smax - Si)}{(Smax - Smin)} \text{ x100} \tag{2}$$

Description:

Si : The actual value achieved for the indicator

Smax : The performance value of the best achievement

Smin : The performance value of the worst achievement

Each indicator score is then converted into a value from 0 to 100. It is important to note that a score of 0 represents the poorest performance, while a score of 100 represents an excellent performance. These values follow the categorization used in the Snorm De Boer method (Hasibuan et al., 2018).

The final stage is analysis and discussion. This analysis involves the results of modeling the coffee supply chain, performance measurement, and recommendations for improvement. From the final value obtained as seen in Table 1, a proposal for improvement is given to address the root cause of the problem in the robusta coffee supply chain in Ulu Belu District. Furthermore, conclusions can be drawn from the results obtained as a basis for making recommendations and suggestions for further research.

Table 1. Supply Chain Performance Standard Value Classification

Perfomance Score	Criteria
95 -100	Excellent
90 - 94	Very good
80 - 89	Good
70 - 79	Fair
60 - 69	Poor
<60	Very Poor

Source: (Syahputra et al., 2020)

3. RESULTS AND DISCUSSION

3.1 Coffee Agroindustry Profile in Ulu Belu District

Tanggamus is the second largest coffee-producing district after West Lampung in Lampung Province. Tanggamus Regency has 20 Districts with a coffee plantation area of 41,552 Ha and a total production of 33,821 tons in 2022 (Statistics Tanggamus Regency, 2024). The area with the most significant coffee production in Tanggamus Regency is Ulu Belu District. On average, coffee trees in Ulu Belu District are 25-30 years old and have a legacy since the 1990s. The age of the coffee tree influences coffee tree production. Coffee plants start to be productive at around 4–5 years of age, peak production between 10–15 years, and their productivity declines after that age. Rejuvenation of plants through techniques such as pruning is highly recommended to maintain optimal yields after the plants have passed their peak productive period. Several farmers in Lampung Province, especially in Tanggamus, have been included in the verification (4C). PT Nestle Indonesia carried out the verification program as a form of corporate social responsibility (CSR). 4C is a level-below certification assessment system to improve coffee quality and farmer welfare and sustain the coffee economy. Coffee farmers in Ulu Belu District have institutions that manage community forests. It functions to improve community welfare by managing resources optimally, fairly, and sustainably (Larasati et al., 2021).

3.2 Respondent Profiles

Respondent profiles offer valuable information about their background, experience, and decision-making patterns in agricultural business operations. The respondents' profiles included age, education level, land area, and experience in the coffee agroindustry. The respondent profile can be seen in Table 2. As seen in Table 2. the average age of farmers in the young age category is 20-40 years (50.000%). and the old age is 51-60 years (23.333%). The age of farmers is related to the application of technology; the young age category is faster in applying new technology and indicators of the level of human resources, productive or not, in running their farming business. Higher education makes it easier to adapt or apply technological developments.

Table 2. Respondent Profile

Characteristics		Number of People	Percentage (%)
Age	20^{th} - 40^{th}	15	50.000
	41^{th} - 50^{th}	8	26.667
	51^{th} - 60^{th}	7	23.333
Education	Elementary school	10	33.333
	Junior High School	9	30.000
	Senior high school	8	26.667
	Bachelor's Degree	3	10.000
Land Area	1 - 2 ha	9	30.000
	3 - 4 ha	14	46.667
	5 - 6 ha	7	23.333
Experience in Coffee's Agroindustry	$<5^{yo}$	5	16.667
	5^{yo} - 10^{yo}	25	66.667
	$>10^{yo}$	5	16.667

The level of education of respondents as coffee farmers in Ulu Belu District is dominated by elementary schools (33.333%). The characteristics of the land area range from 3-4 ha (46.667%). which is included in the large category. According to Amanah (2018), land is one of the important factors in carrying out development. As land area increases, farmers face higher production costs and must earn more to cover those expenses. Financially stable farmers tend to adopt innovations more readily, as their strong economic capacity gives them the confidence and resources to invest in new technologies, methods, and practices. As shown in Table 2, most respondents (66.667%) have 5 to 10 years of experience managing robusta coffee farming. This indicates that they possess a moderate to high level of practical knowledge and are relatively experienced in operating their farming businesses. Despite having a relatively low level of education, experienced farmers can still manage their businesses well (Ariyanti et al., 2019).

3.3 Robusta Coffee Supply Chain Structure in Ulu Belu District

The robusta coffee supply chain structure in Ulu Belu District involves several actors from upstream to downstream: farmers, commodity aggregators, collectors, business partnership or joint business groups (KUB), ground coffee processors, domestic roasters, retailers, exporters, and consumers. Coffee supply chain model in Ulu Belu District can be seen in Figure 1.

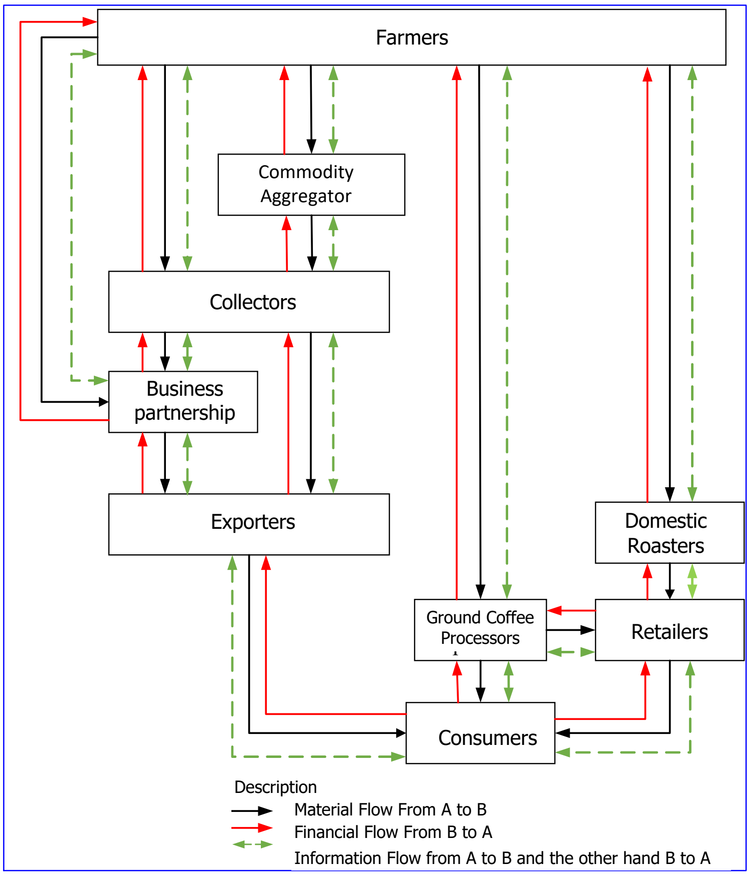

Figure 1. Robusta Coffee Supply Chain Model in Ulu Belu District

1. Information Flow

The flow of information in the coffee supply chain includes information on prices, delivery times, payment systems, quantities, and services between actors in the coffee supply chain. Information related to the coffee supply chain in Ulu Belu District flows from upstream to downstream or vice versa. Information flowing from upstream to downstream is the quantity and quality of coffee supply. Meanwhile, information flowing from downstream to upstream is the price of coffee per kilogram and the quality of coffee (water content, dirt content, size, and smelly beans). The flow of information between farmers and collectors in the robusta coffee supply chain in Ulu Belu has not run smoothly. In the upstream part, the price of coffee obtained by farmers is often delayed, and the amount of market demand is unknown. This is due to a lack of cooperation or partnership between farmers and marketing institutions. Information related to coffee prices is conveyed through online communication with whatsApp, and website.

2. Financial Flow

The financial flow from farmers in each chain ends at the exporter. All actors carry out the payment process with a cash payment system. The cash payment system is used because the distance between farmers and collectors is not far, and farmers need cash for their daily needs. In the buying and selling transaction process, there is a difference in coffee prices between collectors and business partnership when buying coffee from farmers. Collectors buy coffee from farmers for IDR 22,400 per kg, and business partnership buys coffee from farmers for IDR price. 22,500 per kg. Although business partnership has a higher purchase price, farmers prefer to sell to collectors. This is because collectors accept all types of coffee quality, the distribution distance is not too far, and collectors lend capital to farmers. The income received by coffee farmers in Ulu Belu District can be seen in the production of 860 kg/Ha; farmers get a profit of around IDR 15,804 per kg, collectors 470 per kg, and business partnerships 325 per kg. Based on the B/C calculation, it can be seen that farmers get a value of 3.09, meaning that for every IDR 1.00 spent by farmers, they will receive IDR 3.09. The B/C ratio of coffee farming in Ulu Belu District can be said to be profitable. B/C determines the distribution of profits and costs incurred by each supply chain actor (Sylvia & Ismoyowati, 2020). The robusta coffee trading activity in Ulu Belu District has a market form, namely the oligopoly market. This type of market has few collectors and can suppress the price they pay farmers. Coffee pricing is based on several coffee indicators, such as water content and defect value (rotten, black, broken, and brown beans.

3.4 Measuring Coffee Supply Chain Performance in Ulu Belu District

The validation results obtained 12 key performance indicators; the KPI is valid if three respondents answered "yes" to the KPI, and if only two answered "yes," then the KPI is not declared valid. The resulting KPI can be seen in Table 3.

Table 3. Key Performance Indicator (KPI)

No	KPI	Unit
1	Delivery accuracy	%
2	Perfect item condition	%
3	Orders delivered in full	%
4	Cultivation cycle time	Day
5	Shipping cycle time	Day
6	Capacity increase adaptability	%
7	Capacity decrease adaptability	%
8	Capacity increase flexibility	Day
9	Total of supply chain management cost	Rp
10	Cost of goods sold	Rp
11	Profit	Rp
12	Cash-to-cash cycle time	Day

After obtaining the KPI for supply chain performance assessment, the weight calculation is carried out for each KPI using ANP. The coffee supply chain performance measurement network model can be seen in Figure 2. This figure illustrates the network structure connecting SCOR business processes to performance attributes and their associated performance metrics. Each box represents a component of the SCOR model, and the values in parentheses indicate the respective weights. Arrows show the direction of influence from processes to attributes and then to specific metrics, highlighting the integrated nature of performance measurement. Based on the data processing results using ANP, it can be seen that at the business process level, planning has the highest weight with a value of 0.102, and shipping (delivery) has the lowest weight with a value of 0.038. This value is influenced by coffee agro-industry actors who need planning in preparing land for replanting unproductive coffee plants, post-harvest processing, and marketing coffee. Shipping has the lowest value in the business process because this KPI is considered less important than other KPIs. The shipping process will run if farmers or collectors have supplies or stock of coffee to be shipped. Therefore, a better coffee cultivation process is prioritized, starting from plant care, fertilization, pest control, and proper post-harvest processing. This can help increase coffee production while the shipping task will run smoothly if sufficient coffee is available. At the performance attribute level, assets have the highest weight with a value of 0.171, and responsiveness has the lowest weight with a value of 0.024. Assets are an important KPI in robusta coffee performance because they affect the use of technology and machinery in running a farming business. Using machinery and technology in the cultivation process will reduce the cost of coffee plant maintenance, increasing profits. Responsiveness has the lowest value in performance attributes because this KPI is considered no more important. The responsiveness of supply chain actors will run well if human resources understands the cultivation process for the marketing activities of coffee to consumers with existing technology. This can be seen from the many trainings, field schools, and other government and private sector coaching.

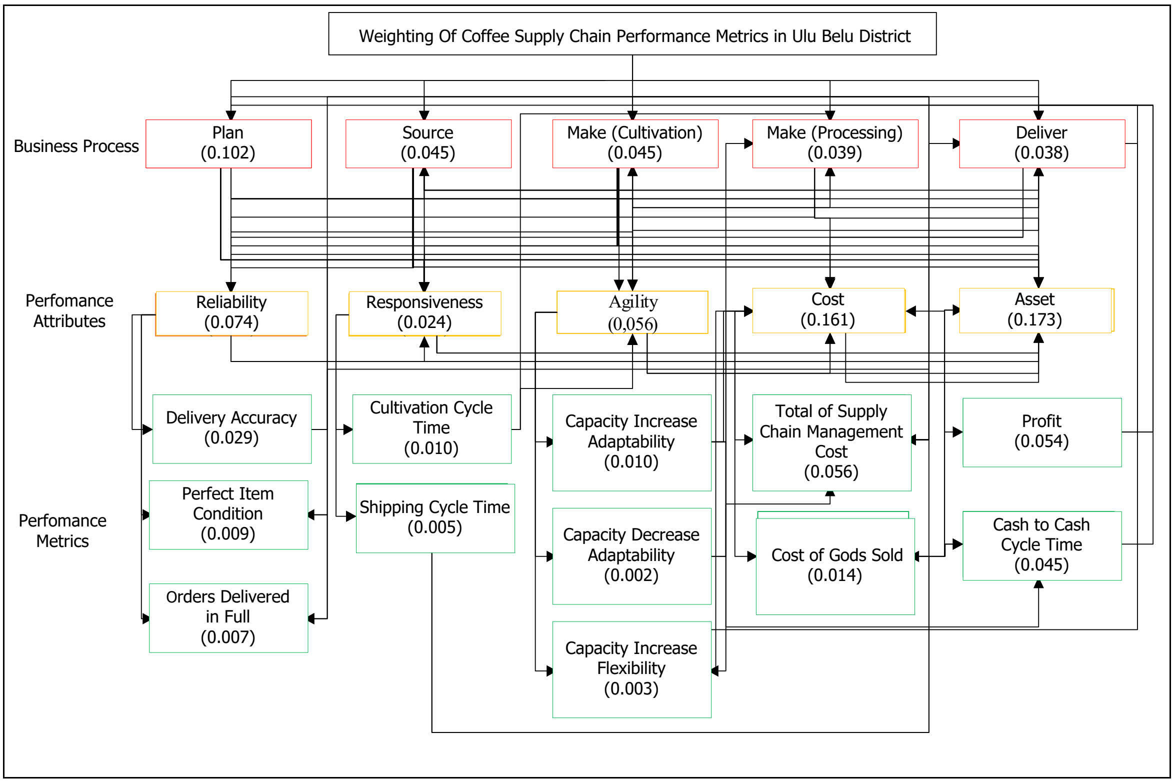

Figure 2. Robusta Coffee Supply Chain Model in Ulu Belu District

3.5 Coffee Supply Chain Performance Measurement Results at Farmer Tier

Most farmers in Ulu Belu District sell coffee as green beans to collectors. Farmers act as producers of robusta coffee for consumption in the downstream sector. Based on the results of performance measurements that can be seen in Table 4, the coffee supply chain in Ulu Belu District is known that farmers get a bad score (59.721). Each key performance indicator influences this score. Based on observations in the field, several farmer performances are less than optimal. The age of coffee trees is pretty old, so coffee production decreases, less fertile coffee land and technology in cultivation, and coffee processing is not maximized in its use. This causes a very low score for coffee farmers in Ulu Belu District.

Table 3 presents the weighted values of key performance indicators (KPIs) related to farmer performance in the robusta coffee supply chain in Ulu Belu District. The performance measurement of the coffee supply chain was carried out by analyzing actual data within the performance matrix and comparing it to the best and worst benchmark values. This comparison produces a performance score for each indicator. The performance matrix was processed using the Snorm de Boer normalization method, which standardises values (parameters) within the KPIs to obtain a comparable score for each indicator. The next stage involved determining the performance score of robusta coffee in the Ulu Belu District by multiplying each normalized score by its respective KPI weight. The results reveal the performance level of each indicator, which is then classified as excellent, very good, good, fair, poor, and very poor. Based on these classifications, further analysis is conducted to identify weak indicators, followed by recommendations for improvement.

Table 4 shows that the performance matrix has the highest weight value on farmer performance, which is influenced by profit factors (26.980) and total management costs (9.086).

The profit matrix (on asset attributes) is an important factor and is highly considered because farmers as coffee producers are oriented towards the profits generated (Prasmatiwi et al., 2017). Profit is an important KPI in robusta coffee performance because the profits obtained by farmers are used to develop their farming businesses. For example, coffee farmers in Ulu Belu have started using modern technology. Using sprayer machines to spray coffee plants and grass-cutting machines makes it easier to clean coffee fields. Using machines in coffee maintenance can reduce maintenance costs, thereby increasing the profits farmers obtain. There is a need to develop coffee cultivation to increase coffee productivity so that the profits are more significant. Long-term coffee development carried out by farmers is the rejuvenation of coffee plants that are 25-30 years old. The use of quality seeds will affect the coffee produced. In addition, according to Pratama (2015), coffee farmers in Ulu Belu stores postpone coffee sales due to fluctuating prices and the uncertainty of the coffee price received by farmers. The advantage of delaying coffee sales is that farmers can obtain a higher coffee selling price, thereby increasing greater profits. This illustrates that coffee farmers have the potential to increase coffee income and have a tremendous opportunity to develop their farming businesses. Total management costs (in cost attributes) are ranked second highest among farmers.

Table 4. Results of Robusta Coffee Supply Chain Performance Measurement

Performance	Weight	Farmers		Collectors		Business Partnership	
		Score	Perfor-mance	Score	Perfor-mance	Score	Perfor-mance
Delivery accuracy	0.122	73.435	8.928	94.400	11.477	92.500	11.246
Perfect item condition	0.036	82.957	2.994	89.600	3.234	76.500	2.761
Orders delivered in full	0.030	69.348	2.072	84.000	2.510	12.500	0.374
Cultivation cycle time	0.039	53.620	2.065	26.667	1.027	41.667	1.605
Shipping cycle time	0.020	100.00	1.987	13.333	0.265	25.000	0.497
Capacity increase adaptability	0.046	61.130	2.834	58.000	2.689	33.000	1.530
Capacity decrease adaptability	0.013	90.000	1.135	32.000	0.404	58.000	0.731
Capacity increase flexibility	0.026	8.885	0.229	21.739	0.559	65.217	1.678
Total of supply chain management cost	0.222	40.956	9.086	20.000	4.437	25.000	5.546
Cost of goods sold	0.037	5.474	0.203	13.532	0.501	17.335	0.641
Profit	0.374	72.087	26.980	94.000	35.181	65.000	24.328
Cash-to-cash cycle time	0.036	33.333	1.208	16.667	0.604	83.333	3.021
Total of Performance		59.721		62.888		53.957	
Average of Performance				58.855 (Very Poor)			

According to Mulyanti (2017), financial management is the management of financial functions such as obtaining and using funds. Financial management plays a role in providing critical information that helps develop and implement strategies in a business. Total management costs in Ulu Belu can be described as forming farmer organizations and managing farming businesses. Farmer groups provide training such as minimizing coffee maintenance costs and marketing management; also, there are certified coffee farmers. According to Marindra (2018), the total cost of plant maintenance incurred by certified farmers is lower than that of non-certified farmers, with certified farmers' farming costs of IDR 4,722,059 while non-certified farmers are IDR 8,383,768 per hectare per year. The high costs are due to the use of chemical pesticides and the use of labor. The costs incurred by farmers in maintaining coffee plants until harvest are pruning costs, fertilizer purchase costs, harvesting costs, drying costs, and shipping costs.

Table 4 shows that the flexibility of increasing capacity (0.229) and the cost of goods sold (0.203) have low values on farmer performance. The value of the KPI flexibility of increasing capacity shows that farmers are less able to meet unplanned consumer demand increases for 30 days. This condition needs to be evaluated from upstream to downstream with the chain member with the lowest value, namely farmers. For example, good coffee cultivation has not balanced the increase in coffee shop businesses that require coffee as a raw material. Limited machines in coffee processing (coffee skin peeling machines/hullers, roasting machines, sorting machines, grinding machines), low levels of farmer human resources in applying cultivation and processing technology, and coffee trees are more than 25 years old (Darwis et al., 2020). This is what causes farmers in Ulu Belu to be less able to meet unplanned consumer demand increases. The second KPI with the lowest value is the cost of goods sold (in the cost group). This KPI is considered less important than other KPIs.

The price received by coffee farmers in Ulu Belu fluctuates quite a bit. Farmers often experience delays in information on changes in coffee selling prices (time lag). This can cause the price farmers receive to be lower than the prevailing price, especially for farmers who provide a deferred payment system. In addition, coffee farmers still process coffee traditionally, such as during harvesting and processing activities. Farmers generally sell coffee with quality coffee beans picked carelessly, high water content, and defective coffee beans (coffee beans that are not whole or broken, hollow beans, odd-shaped beans, hollow beans, beans that have no aroma, and blackened beans). Defective coffee beans and those with high water content cause the selling price to collectors to be lower. Good coffee beans have a water content of around 12%.

3.6 Coffee Supply Chain Performance Measurement Results at the Collector Tier

Coffee collectors in Ulu Belu District play a role in collecting coffee from farmers to be sold to business partnerships. Based on the results of measuring the performance of the coffee supply chain in Ulu Belu District in Table 4, it is known that collectors get a poor score (62.888). Field observations show that the cause of the collector's poor performance is that collectors running their coffee buying and selling business have problems related to coffee quality. The quality received by collectors is randomly picked and has a relatively high water content. Coffee collectors have limited coffee storage warehouses and limited coffee processing machines (coffee skin peeling machines/hullers, roasting machines, sorting machines, grinding machines). The performance matrix has the highest weight value, seen in Table 4, in collector performance, which is influenced by profit factors (35.181) and delivery accuracy (11.477). KPI (on asset attributes) is an important and highly considered factor. According to Dewi (2015), profit can positively affect a business's quality. If a business experiences profit growth, it indicates that the financial performance of the business is in good condition.

Collectors manage transportation in marketing coffee so that they can get big profits. When marketing coffee, collectors spend money on transportation, loading and unloading coffee, and drivers. Collectors reduce transportation costs by planning and scheduling in selling coffee. For example, collectors sort based on grade to get a high price. Coffee sales in Ulu Belu are carried out every three days from collectors to business partnerships. This can reduce transportation costs, and collectors can generate big profits. Delivery accuracy (on the reliability attribute) is ranked second in collector performance; this KPI measures orders sent completely and on time as agreed. According to Marfuah (2021), delivery accuracy is the main goal and challenge that needs to be faced. Another thing that needs to be considered in delivery accuracy is the collaborative relationship between suppliers to create an effective chain.

Farmers send coffee to collectors with coffee quality that is not too low. Collectors receive various types of coffee, such as random and red-picked coffee. On average, coffee sent by farmers to collectors has a water content that is not too high and by the established standards. This is because farmers in Ulu Belu have little understanding of good coffee processing. Agricultural extension workers (PPL) and the coffee industry provide an understanding of coffee processing, which provides field schools. Farmers and collectors in Ulu Belu have good working relationships and communication, such as collectors overseeing several farmer groups in Ulu Belu, and coffee farmers get raw materials from collectors, such as insecticides, fertilizers, and agricultural equipment. Good working relationships and communication between farmers and collectors will impact the quality of coffee sent to partnership business. This is in line with Soka's opinion (2017), which is that farmers need to communicate with consumers to ensure that the coffee is by the quality and quantity of the order and that there are no errors in the information on the quantity of coffee sent. Table 4 shows that the performance matrix of the delivery cycle time (0.267) and the adaptability of capacity reduction (0.404) have a value low on collector performance. Delivery cycle time is the time needed to deliver products to consumers. This KPI is considered less important than other KPIs because farmers experience delays in sending coffee to collectors. Farmers need three days in one week to send coffee to collectors. This is the cause of collectors experiencing delays in sending coffee to partnership business.

The delay in the delivery process is due to the length of the drying process carried out by farmers. The drying process depends on unpredictable weather. Coffee drying is carried out on tarpaulin-covered land, and the land for coffee drying is limited. This causes farmers to take longer in the manual drying and sorting, which takes a long time in the delivery cycle. The adaptability of capacity reduction has a low value because several SCOR performance measurement results have a value of 0, meaning that no supply chain actors have requested a reduction or agreed to a reduction in capacity. The problem so far is not because the product is not finished but because of the scarcity of the product (Diah & Syarief, 2016). Coffee farmers in Ulu Belu do not want a decrease in coffee capacity. However, farmers have problems with marketing, namely that the coffee produced is sold individually so that it gets a low price. Small sales capacity and traditional marketing methods by word of mouth.

3.7 Coffee Supply Chain Performance Measurement Results at Business Partnerships (KUB) Tier

Business partnerships in Ulu Belu District plays a role in storing and sending coffee to exporters. Based on the coffee supply chain performance measurement results, which can be seen in Table 4, it is known that business partnerships received a very poor score (53.957). Based on the performance measurement results, business partnerships has several problems: farmers prefer to sell coffee to collectors rather than to business partnerships, limited coffee bean storage warehouses, and fluctuating coffee prices occur quickly. In addition, inappropriate transportation facilities, long distances, and poth/oled road conditions can result in high transportation costs. The performance matrix has the highest weight value, which can be seen in Table 4 on business partnerships performance, which is influenced by profit factors (24.328) and accuracy of delivery (11.246). Profit KPI (in asset attributes) is an important and highly considered factor. According to Madani et al. (2022), profit is the primary goal of forming every business entity or company. One method to gain profit is to pay attention to sales volume and reduce operational costs incurred. Business partnerships plays a role in increasing the added value of robusta coffee distributed to exporters. Increasing the added value is done by applying processing techniques using drying and sorting machines. Modern drying techniques can produce coffee quality that meets export requirements with a minimum water content of 12%. The processing techniques used by business partnerships can increase the profits obtained. Delivery accuracy (on the reliability attribute) is ranked second in business partnerships performance. The KPI for delivery accuracy is an important factor and is highly considered. Collectors in Ulu Belu work with business partnerships to meet coffee needs, so collectors send coffee to business partnerships according to the agreed quality. Business partnerships guides farmers regarding post-harvest coffee processing to obtain quality that meets export standards. In addition, the role of the government in improving the quality of coffee exports and post-harvest coffee technology is stated in Regulation Number 52/Permentan/OT.140/9/2012 and the coffee export policy, namely ISCOffee.

Based on the description, business partnerships always tries to improve the quality of coffee by conducting coaching, such as field schools related to coffee plant care, reducing the use of chemicals, and better post-harvest coffee processing. The KPI with the lowest value is the order fully delivered, and the delivery cycle time at business partnerships has a value of 0.374 and 0.497, which can be seen in Table 4. The order is fully delivered, and the delivery performance is assessed in complete and timely conditions according to the agreement. This KPI is not considered more important than other KPIs because the business partnerships has formed functions to store and sell coffee before it is sold to consumer. business partnerships sends coffee to exporters twice a week and ships around 27 tons of green bean coffee. Business partnerships has limitations in storing coffee due to the smaller storage capacity of the warehouse. Therefore, the coffee storage stock owned by business partnerships is relatively small. Coffee stored in poor conditions can cause damage, such as increased water content and mold growth. The damage to the coffee occurs due to biotic factors (insects, microorganisms) and abiotic factors (humidity and temperature).

The second KPI with the lowest value is the delivery cycle time (in the responsiveness group). This KPI is considered no more important than other KPIs. Geographically, Tanggamus Regency, as a coffee-producing area, has a flat to hilly topography. In addition, business partnerships sends coffee from Ulu Belu to exporters in Bandar Lampung, which covers a relatively long distance of 99.5 km. The long-distance and narrow and slightly potholed road access results in the delivery of coffee from business partnerships to exporters taking a longer time, approximately 2 days. In addition, coffee farmers tend to sell coffee when they get a suitable price. If the selling price of coffee is low, farmers in the Ulu Belu store postpone sales activities, resulting in business partnerships having a shortage of coffee to send to exporters. Another reason is that the coffee harvest in Ulu Belu differs in each village; for example, Datarajan village has a different coffee harvest time from Sukamaju village by about 1 month. If a complete recapitulation occurs, the performance results of coffee agro-industry actors in Ulu Belu will get a performance value that falls into the very poor criteria (58.855), as seen in Table 4.

3.8 Strategy for Improving Robusta Coffee Supply Chain Performance in Ulu Belu District

Based on the results of performance measurements of 12 KPIs that require improvement. Recommendations for improvement are prepared to address problems in the coffee supply chain in Ulu Belu District. Based on the results of performance measurements, KPIs with poor performance values can be improved, and KPIs with reasonably good performance can be improved. Analysis of performance indicators and performance improvement strategies can be seen in Table 5.

Table 5. Analysis of Performance Indicators and Performance Improvement Strategies

Problem	Strategy	Description
Profit (RA-1) Low profits for farmers, collectors, and business partnership	a. Farmer: Implementation and supervision of Good Agricultural Practices (GAP) and Good Handling Practices (GHP). b. Collectors and Business Partnership: Facilitate communication and coordination among supply chain participants.	Providing training and coaching to farmer groups related to GAP and GHP
Total management cost (DC-1) High coffee agro-industry management costs	a. Farmers: Implementation of the Common Code for the Coffee Community (4C) and GAP certification b. Collectors and Business Partnership: Delivery scheduling planning	Using organic fertilizers gradually. Moreover, an integrated pest control (IPM) system should be implemented. Set the shortest delivery schedule and route for coffee to customers
On-time delivery (PR-1) Relatively low coffee quality	Farmers, Collectors and Business Partnership: Implementation of Good Agricultural Practices	The integration of GAP among these actors helps strengthen supply chain performance by improving efficiency, enhancing product quality, and promoting long-term sustainability in coffee production.

Problem	Strategy	Description
Adaptability of capacity increase (MA-1) Low availability of coffee owned by supply chain actors	Farmers, Collectors and Business Partnership: Implementation of GAP and increasing storage or warehouse capacity	a. Farmers: The implementation of replanting on coffee plantations is not done comprehensively but gradually. b. Collectors and Business Partnership: Making additions and expansions to the coffee storage warehouse to increase the amount of coffee inventory
Processing/Cultivation cycle time (SRe-1) Delays in coffee harvesting due to extreme weather.	a. Farmers:Planting of superior coffee seedlings and replanting b. Collectors and Business Partnership: Adding coffee processing equipment	Farmers carry out cuttings using local clones, implementing replanting in stages.
Cost of goods sold (DC-2) Fluctuating coffee prices and low-quality coffee produced by farmers	a. Farmers: Training and reachout on GAP. b. Farmers, Collectors and Business Partnership: Improving coordination and communication between supply chain actors	Coffee farmers work together with the plantation office and the private sector so that they can conduct reachout related to red picking and farmers get high prices.
Cash to cash cycle time (RA-2) Payment of supply chain actors is a relatively long	Farmers, Collectors and Business Partnership: Implementation of Collaborative Planning, Forecasting, and Replenishment (CPFR) in supply chain management in Ulu Belu.	Creating an information system to anticipate coffee supplies, production, and transportation can achieve safe stock and stable coffee prices.
Perfect condition of goods (PR-2) Farmers do not send coffee according to customer specifications.	Farmers, Collectors and Business Partnership: Implement CPFR Moreover, replenishment of stock in advance	Building good relationships between supply chain actors.
Orders fully delivered (PR-3) Farmers postpone sales or store coffee.	Farmers, Collectors and Business Partnership: Determining safety stock	Slowly increase coffee inventory to prevent delayed order deliveries from suppliers.
Flexibility of capacity increase (MA-3) Limitations of machines, human resource level in technology application and age of coffee trees more than 25 years	Farmers, Collectors and Business Partnership: Building partnerships between coffee farmers and the coffee industry	To address machine limitations, low technological capacity, and ageing coffee trees, farmers, collectors, and business partners should build strong partnerships with the coffee industry to support capacity enhancement.
Delivery cycle time (SRe-2) Each pekon has a different coffee harvest and long distances and narrow and potholed road access.	Farmers, Collectors and Business Partnership: Planning and scheduling of deliveries	Due to varying harvest times and poor road access in each village, farmers, collectors, and business partners need to plan and schedule deliveries effectively.

Problem	Strategy	Description
Adaptive capacity decline (MA-2) Decrease in the quantity of coffee produced	a. Farmers: Farmers do coffee cuttings using local clones that are more resistant to weather changes. b. Farmers, Collectors and Business Partnership: Increasing the target market and providing training to increase the added value of coffee	A key strategy involves farmers using local coffee clones that are more resilient to climate change. In contrast, collaboration among farmers, collectors, and business partners focuses on expanding target markets and providing training to enhance the added value of coffee products.

3.9 Managerial Implications of GAP and GHP

Performance improvement strategies for the robusta coffee supply chain in Ulu Belu District as regulated in the Regulation of the Minister of Agriculture Number: 49/Permentan/OT.140/4/2014 concerning GAP (Good Agriculture Practices) and Regulation of the Minister of Agriculture Number: 52/Permentan/OT.140/9/2012 concerning GHP (Good Handling Practices) that need to be implemented. This is done to improve the quality, productivity, and selling price of coffee. Crop cultivation activities (GAP) include the post-harvest handling process, post-harvest infrastructure and facilities, quality standards, environmental preservation, and supervision. Post-harvest handling of coffee (GHP) with the scope of sustainable coffee production, good coffee cultivation, diversification in coffee cultivation, harvesting, and post-harvest handling. The principles of GAP and GHP in coffee plantations can assure consumers through efficient, productive, and environmentally friendly processes. Based on the problems in the robusta coffee supply chain in Ulu Belu District, improvements need to be made through counseling on the Implementation and supervision of GAP and GHP as follows:

1. Conducting technical guidance for robusta coffee GAP on selecting superior seeds appropriate for the planting environment to obtain maximum taste quality and productivity.
2. Carrying out a combination of clones that are specifically suited to the environment, it is better to use grafted clone seeds using the BP 308 clone rootstock that can survive parasitic nematodes.
3. Reducing dependence on chemical fertilizers by composting with coffee plantation waste (coffee skin and organic waste).
4. Intercropping plants are selected plants that do not have a canopy that is not too dense and have small leaves to provide good light.
5. Harvesting good quality coffee is indicated by a change in the color of the skin of the Robusta coffee fruit to red while harvesting unripe fruit (green and yellow fruit) will cause the quality of the beans to decrease and the taste to be less good.
6. Coffee beans that have been harvested and sorted must be dried immediately so that a chemical process that causes a decrease in quality does not occur. In the highlands, coffee is dried for 2-3 days until the water content reaches 25-27%, with a drying layer thickness of around 6-10 cm. Drying can be done using racks, tarpaulins, and drying floors.
7. Post-harvest coffee handling facilities and infrastructure are used to obtain high-quality post-harvest results (pulper machines, washing machines, drying machines, peeling machines or hullers, and sorting machines).

4. CONCLUSIONS

Based on the results of the coffee supply chain performance measurement, the following conclusions can be drawn. In the coffee supply chain structure in Ulu Belu District, there are several actors: farmers, collectors, collectors, business partnerships, ground coffee processors, domestic roasters, retailers, exporters, and consumers. The coffee supply chain has six types of distribution channels. The most common distribution channels are from farmers as the starting point of the supply chain (point of origin), collectors, business partnerships, exporters, and consumers (point of destination). The measurement results based on 12 key performance indicators show that the coffee supply chain in Ulu Belu District is still performing poorly (58.855). The results of performance measurements at each tier of the coffee supply chain show that farmers (59.721) are in poor condition, collectors (62.888) are in deplorable condition, and business partnerships is in poor condition (53.957). Strategies needed to improve the performance of the coffee supply chain in Ulu Belu District include socialization related to the implementation of Good Agricultural Practices (GAP), implementation and supervision of GAP and Good Handling Practices (GHP), implementation of the Common Code for the Coffee Community (4C) certification, implementation of Collaborative Planning, Forecasting, and Replenishment (CPFR) in supply chain management in Ulu Belu, increasing storage warehouse capacity, determining safety stock and planning delivery scheduling.

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Development and Priority Selection of Marketing Strategies for Pangas Catfish Skin Chips at Gatiga Snack MSMEs

Eka Novriyanti[1], Teny Sylvia*[1], and Noveliska Br Sembiring[1]
[1]Department of Agricultural Industrial Technology, Faculty of Industrial Technology, Sumatera Institute of Technology, Terusan Rya Cudu St., Way Hui, Jati Agung, South of Lampung, Indonesia
Email: teny.sylvia@tip.itera.ac.id*

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Abstract

Gatiga Snack MSMEs, a chip producer in South Lampung, faces tough competition and requires effective marketing strategies to grow. This study aims to develop and select strategies that can be implemented by Gatiga Snack using SWOT analysis and QSPM. Based on the SWOT analysis results, 18 recommended strategies were obtained. These strategies are then prioritized using QSPM analysis. There are three recommended strategy implementation periods. In the first period, six strategies were recommended that could be implemented. The highest TAS score among the strategies in the first period was forming a special marketing team for managing the Gatiga Snack MSME business (WO4), amounting to 7.296. In the second period, six strategies were also recommended that could be implemented. An intensive promotional strategy by creating a schedule of online and offline routine promotional activities (WO2) resulted in the highest TAS score of 7.141 in the second period. The third-period strategy consisted of six strategies with the highest TAS score of 7.031, namely building a brand image by making reviews or testimonials about the quality of Pangas Catfish Skin Chips's Gatiga Snack so that new consumers would trust and be interested in buying (ST3).

Keywords: *Fish Skin Chips, Marketing Strategy, Pangas Catfish, QSPM, SWOT*

1. INTRODUCTION

Economic development in Indonesia is increasingly rapid due to globalization and free markets, causing intense business competition. Companies must be adaptive to survive and compete in the business world. One way for companies to be adaptive is to have a competitive advantage (Wiwoho, 2019). Developing the right marketing strategy is one way to create a competitive advantage. One business requiring a marketing strategy is the Gatiga Snack MSMEs in Banjar Agung, South Lampung. Gatiga Snack MSME has several products, including pangas catfish skin chips, bitter melon chips, banana chips, etc. One of the superior products of Gatiga Snack MSMEs is pangas catfish skin chips, which are branded "Fish Skin Gatiga." This pangas catfish fish skin is unique compared to other processed chip products, namely that the raw materials used are by-products from companies that process pangas catfish fillets. Pangas catfish skin has a high selling value when used as a chip product (Noviani & Wahyuni, 2019). Utilizing pangas catfish skin waste is a good business opportunity for Gatiga Snack MSMEs because it can increase the added value of the products produced.

Sales at Gatiga Snack MSME experienced fluctuations from 2021 to 2023. From September 2021 to August 2022, the lowest sales of pangas catfish skin chips were 48 packages, and the highest was 218 packages. Then, from September 2022 to August 2023, the lowest sales of pangas catfish skin chips were 123 packages, and the highest was 852 packages. The difference between the amount of demand and the supply of products sold causes this fluctuation condition. Gatiga Snack, a micro, small, and medium enterprise (MSME), employs a hybrid production approach that integrates make-to-stock and make-to-order systems. While the enterprise primarily prioritizes the make-to-order model servicing orders from partner souvenir shops the production and inventory

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levels remain inconsistent. This inconsistency arises due to the variability in order volumes, which are heavily influenced by the partners' estimations of consumer demand. Such estimations tend to fluctuate, particularly increasing during the periods leading up to religious holidays, thereby adding further unpredictability to the production process. Gatiga Snack transitions to a make-to-stock approach without partner orders, producing inventory intended for display and sale through its marketing channels. However, this reactive shift between production systems contributes to uncertainty in product availability and results in fluctuating sales figures. The lack of a stable and predictive production and inventory strategy poses significant operational challenges, especially in aligning supply with actual market demand.

Based on the problems in the Gatiga Snack MSMEs that have been described, a marketing strategy is essential so that marketing the pangas catfish skin chips of Gatiga Snack product can be carried out optimally. The methods that can be used to develop marketing strategies in this research are SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) and Quantitative Strategic Planning Matrix (QSPM). SWOT analysis analyzes internal and external factors in a business to obtain alternative strategies. Recommendations for alternative strategies obtained from the SWOT analysis cannot be implemented simultaneously, so it is necessary to prioritize the strategies that will be implemented. QSPM is a decision-making method that can provide a weighting of alternative strategies (Sianturi, 2020).

2. MATERIAL AND METHODS

This research is a case study on Gatiga Snack MSMEs located on Jl. Ryacudu Canal, Banjar Agung Village, Kota Baru, South Lampung. The object of this research is the marketing strategy for "Pangas Catfish Skin Chips" products in Gatiga Snack MSMEs. Marketing strategy is a company's planned actions to have a competitive advantage in achieving goals (Hartono & Maligan, 2020). The method used in this research is SWOT analysis and QSPM. SWOT analysis is a simple method of preparing marketing strategies by analyzing internal and external conditions in an organization or company. The components of SWOT analysis are strengths, weaknesses, opportunities, and threats (Sundari et al., 2022). SWOT analysis is carried out on marketing mix variables. A marketing mix is a collection of variables to target markets to achieve goals. The marketing mix has seven variables: product, price, place, promotion, people, process, and physical evidence. (Riyono & Budiharga, 2016). Apart from that, this research will prioritize strategies using QSPM. QSPM is a method for objectively evaluating strategic alternatives to obtain optimal results. This method determines marketing strategy priorities that can be applied to a business (Shelinda et al., 2021).

This research data was collected using a non-probability sampling technique, and the type of sampling was a purposive sampling technique. This research used a sample size of 30 internal and external respondents. The internal respondent consists of the owner and the employee; the external respondent is the customer. The types of data needed are primary data and secondary data. The research stages can be seen in Figure 1.

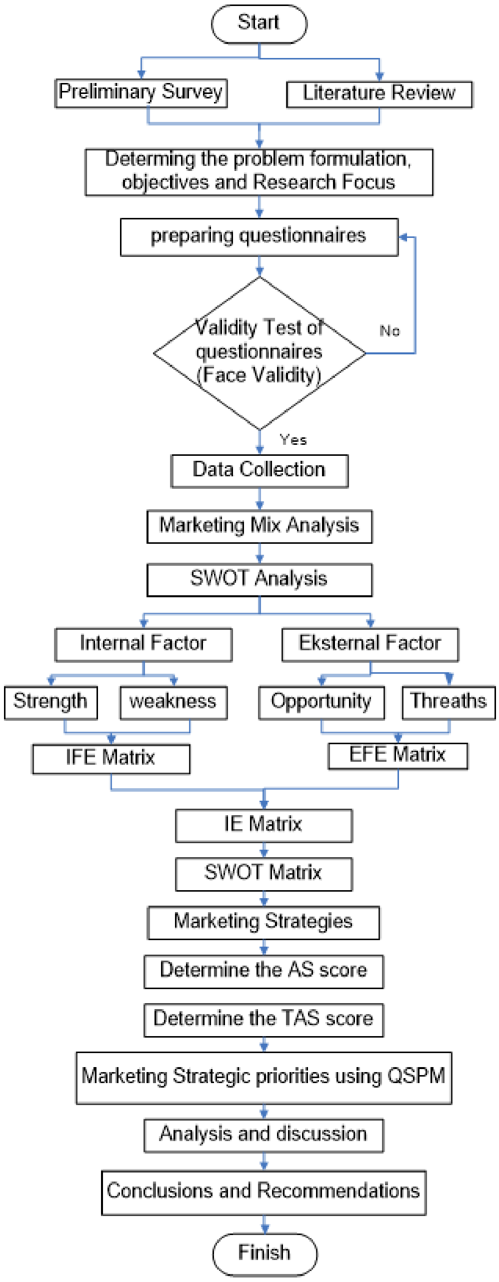

Figure 1. Research Stages

3. RESULTS AND DISCUSSION

3.1 General Description of Gatiga Snack MSMEs

Gatiga Snack MSMEs is a business founded by Mr. Rahmat Ibnu Mas'ud in January 2020. Mr. Rahmat started his business with Rp capital. 500,000- at that time, the first product was bitter melon chips. Mr. Rahmat's bitter melon chips product business has been growing over time. The development of the bitter melon chips business made Mr. Rahmat take the initiative to produce other types of chips, namely pangas catfish skin chips, banana chips, opak (fried crispy chip made from a roll of steamed rice or cassava), and prawn klanting. Gatiga Snack MSMEs produces around 50 to 100 kg of raw materials for pangas catfish skin every month. The production process in MSMEs is carried out only a few times a week because it considers the amount of product inventory in the sales window. This "Pangas Catfish Skin Chips" product can be found directly at Gatiga Snack MSMEs or souvenir shops in Bandar Lampung.

3.2 Develop a Gatiga Snack MSME Marketing Strategy Using SWOT Analysis

A. Internal Factor Analysis

Based on Table 1, it can be seen from the IFE matrix that the strengths score is greater than the weaknesses, which means that Gatiga Snack MSMEs can use their strengths to overcome weaknesses. According to Setyowati & Khoiriyah (2020), a company's internal capabilities are between 3.00-4.00 on the IE matrix, meaning the company can use strengths to overcome weaknesses.

Table 1. Internal Factor Evaluation

IFE	Weight	Rating	Score
Strength			
Gatiga Snack MSMEs has a business permit (P-IRT)	0.087	3.700	0.323
Gatiga Snack MSMEs has a halal certificate to provide a guarantee of halal products	0.092	3.867	0.354
The owner of the Gatiga Snack MSMEs helps reduce waste pollution by processing pangas catfish skin waste from fish fillet companies.	0.074	3.633	0.269
Gatiga Snack MSMEs products have a long shelf life.	0.073	3.367	0.247
Gatiga Snack MSMEs provides discounts for purchasing products in specific quantities	0.081	3.533	0.288
Gatiga Snack MSMEs offers bundling package products	0.075	3.300	0.246
The owner of Gatiga Snack MSME understands how to manage accounts on e-commerce and social media for selling online and as a means of promotion	0.071	3.400	0.241
Gatiga Snack MSMEs responsively provides good service to customers in e-commerce	0.080	3.500	0.279
Total of strength	0.632	28.30	2.245
Weakness			
The "Pangas Catfish Skin Chips" of Gatiga Snack product only has one packaging weight variation	0.066	3.167	0.208
Promotional activities carried out by Gatiga Snack MSMEs are not yet optimal online	0.077	3.467	0.267
The location of Gatiga Snack MSMEs is less strategic	0.068	3.400	0.232
Lack of workforce for the Gatiga Snack MSME marketing team	0.080	3.500	0.281
Soft skills for product offering copywriting are still lacking	0.076	3.433	0.262
Total of weakness	0.368	16.967	1.250
Total	1.000	45.267	3.495

The first highest strength factor is "having a halal certificate to guarantee product halalness." Halal certification impacts a business because it needs to guarantee the halalness of its products; apart from that, halal certification is mandatory based on the provisions of the MUI institution (Ningrum, 2022). Furthermore, the second highest factor is "Gatiga Snack MSMEs have a business permit (P-IRT)." A business permit (P-IRT) is helpful as a guarantee of legal protection for the continuity of developing a business (Kusmanto & Warjio, 2019). The third highest factor is "Gatiga Snack MSMEs provide discounts." Price discounts can create customer loyalty because they get cheaper than average (Mela et al., 2020).

The first weakness is the "lack of manpower for the marketing team." The role of employees is vital, especially their abilities according to their field because they influence the success of strategic factors. The second highest threat factor "is "the online promotional activities carried out are not optimal" Promotions will not run optimally if a business has limited employees in the marketing field, which can affect the success strategy if it is not carried out optimally. (Setyowati & Khoiriyah, 2020). The third highest threat factor is "soft skills for product offering copywriting are still lacking." The success of promotional activities can run well if the word processing of the offer copywriting is made attractive to encourage customers to buy the products offered (Handini & Choiriyati, 2020).

B. External Factor Analysis

Based on Table 2, the opportunity score results are more significant than the threats. In this case, Gatiga Snack MSMEs respond more to opportunities than threats. Companies with an excellent external position respond to more opportunities than threats and are between 3.00-4.00 on the Setyowati & Khoiriyah (2020) EFE table score.

Table 2. External Factor Evaluation

EFE	Weight	Rating	Score
Opportunity			
Customers who are satisfied with Gatiga Snack products do repurchase	0.110	3.667	0.405
Having resellers expand the market share of Gatiga Snack products	0.107	3.867	0.415
Advances in digital markets make it easier for people to shop online	0.108	3.700	0.400
Social media as a promotional tool for Gatiga Snack MSMEs to attract more consumers	0.111	3.733	0.415
There is support from the government for MSMEs	0.103	3.633	0.373
Total of opportunity	0.540	18.600	2.008
Threats			
The existence of shipping costs in e-commerce has the potential to reduce consumers' interest in shopping online.	0.083	3.367	0.281
Damaged products and packaging can impact MSME Gatiga Snack store reviews on e-commerce.	0.103	3.667	0.379
Competitors who have more vital branding	0.087	3.300	0.289
Competitors are more aggressive in promoting similar products	0.092	3.533	0.326
Loss of customers due to unsatisfactory quality of service provided	0.094	3.600	0.338
Total of threats	0.460	17.467	1.612
Total	1.000	36.067	3.620

The first highest opportunity factor is "social media as a promotional tool for Gatiga Snack MSMEs to attract more consumers". Online promotion via social media can make business more accessible because it does not require costs, energy, and time. The second highest opportunity factor is "having resellers expand the market share of Gatiga Snack products." The more resellers, the more excellent the opportunity for people to know about a product (Puspitarini & Nuraeni, 2019). Then the third opportunity factor is "the existence of support from the government for MSMEs". The government's role in supporting MSMEs is influential because it helps improve human resource capabilities and increase entrepreneurial spirit and tremendous skills (Mersita et al., 2019).

The first threat factor is that "damaged products and packaging can impact MSME Gatiga Snack store reviews on e-commerce." Store reviews on e-commerce can influence potential new consumers' purchasing decisions (Mersita et al., 2019). "Losing customers due to unsatisfactory quality of service provided" is the second threat factor. This fast response from the seller can maintain loyalty because the service obtained is in line with consumer expectations (Putra et al., 2017). Then the third highest threat factor is "competitors are more aggressive in promoting similar products." The more promotions competitors carry, the higher the attractiveness of consumer buying interest (Mersita et al., 2019).

1. Matirx IE

Based on the results, the average IFE value is 3.495, and the average EFE value is 3.620. The position of Gatiga Snack MSMEs is in cell I, namely grow and build, which can be seen in Figure 2, meaning that Gatiga Snack needs a strategy to grow better and develop its business to be more advanced. The strategies that MSME Gatiga Snack can implement are intensive strategies and integration strategies (Setyorini et al., 2016). An intensive strategy can be carried out by developing a broader market reach. Meanwhile, integration strategies can be carried out by focusing on being able to compete with other competitors (Halimah et al., 2020).

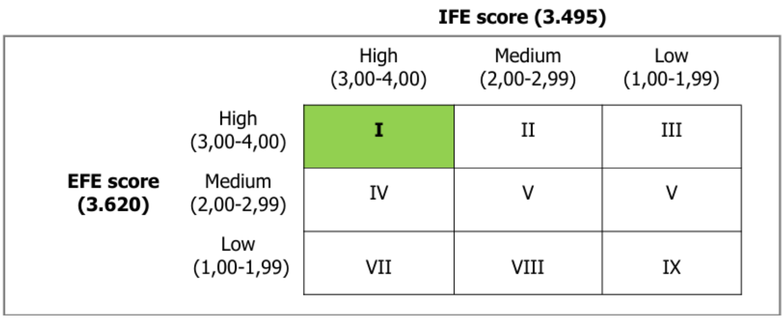

Figure 2. IE Matrix

2. SWOT Matrix

The SWOT Matrix is a matrix that combines internal and external factors to create strategies for optimizing and improving business. The SWOT matrix can clearly describe the external opportunities and threats faced by Gatiga Snack MSMEs and adjust their strengths and weaknesses. The following are the results of the SWOT strategy combination planning matrix, which can be seen in Table 3.

Table 3. SWOT Matrix

	Strength	Weakness
	1. Gatiga Snack MSMEs has a business permit (P-IRT) 2. Gatiga Snack MSMEs has a halal certificate to provide a guarantee of halal products 3. The owner of the Gatiga Snack MSMEs helps reduce waste pollution by processing pangas catfish skin waste from fish fillet companies. 4. Gatiga Snack MSMEs products have a long shelf life. 5. Gatiga Snack MSMEs provides discounts for purchasing products in specific quantities 6. Gatiga Snack MSMEs offers bundling package products	1. The "Pangas Catfish Skin Chips" of Gatiga Snack product only has one packaging weight variation 2. Promotional activities carried out by Gatiga Snack MSMEs are not yet optimal online 3. The location of Gatiga Snack MSMEs is less strategic 4. Lack of workforce for the Gatiga Snack MSME marketing team 5. Soft skills for product offering copywriting are still lacking

	Strength	Weakness
	7. The owner of Gatiga Snack MSME understands how to manage accounts on e-commerce and social media for selling online and as a means of promotion 8. Gatiga Snack MSMEs responsively provides good service to customers in e-commerce.	
Opportunities	SO Strategy	WO Strategy
1. Customers who are satisfied with Gatiga Snack products do repurchase 2. Having resellers expand the market share of Gatiga Snack products 3. Advances in digital markets make it easier for people to shop online 4. Social media as a promotional tool for Gatiga Snack MSMEs to attract more consumers 5. There is support from the government for MSMEs	1. Expand the marketing area for Gatiga Snack products by utilizing business permits (P-IRT) and halal certificates to increase sales. 2. Increase and establish collaboration between Gatiga Snack MSME owners and resellers. 3. Join communities about e-commerce and social media. 4. Place paid advertisements on social media platforms to increase brand awareness of Gatiga Snack products. 5. Create content that involves interaction between Gatiga Snack and the audience on social media to increase customer engagement and maintain consistency in advertising posts. 6. Take advantage of support from the local government by actively participating in the government's MSME activities, such as opening a stand to introduce Gatiga Snack products.	1. Added variations in product packaging weight and taste to the pangas catfish skin chips of Gatiga Snack product 2. Intensive promotion by creating a regular schedule of promotional activities both online and offline. 3. Open a private outlet strategically or place it in a gift shop so that Gatiga Snack products are easily accessible to consumers. 4. Form a special marketing team to manage the Gatiga Snack MSME business. 5. Improve your ability to read the market to create copywriting on social media.
Threats	ST Strategy	WT Strategy
1. The existence of shipping costs in e-commerce has the potential to reduce consumers' interest in shopping online.	1. Offer discounts, cashback and flash sales to attract consumers at e-commerce promotional events.	1. Improve the management of Gatiga Snack MSMEs in the marketing department.

	Strength	Weakness
2. Damaged products and packaging can impact MSME Gatiga Snack store reviews on e-commerce. 3. Competitors who have more vital branding 4. Competitors are more aggressive in promoting similar products 5. Loss of customers due to unsatisfactory quality of service provided.	2. Improve good service to maintain consumer comfort by providing Gatiga Snack products that are always available. 3. Build a brand image by making reviews or testimonials about the quality of Gatiga Snack products so that new consumers will trust and be interested in buying. 4. Maintain the product's price, quality and taste so that it can compete with similar products.	2. Evaluate the performance of Gatiga Snack MSMEs. 3. Create a mascot identical to the Gatiga Snack MSME to strengthen its identity.

3.3 Marketing Strategy Priorities for Pangas Catfish Fish Skin Chip of Gatiga MSME using QSPM

TAS is the result of multiplying each internal and external factor's weight by the attractiveness score assigned to each strategy. It reflects how attractive and appropriate a strategy is when considering the SMSE's internal strengths and weaknesses, as well as external opportunities and threats. A higher TAS indicates a more favorable and implementable strategy. Based on the SWOT matrix, 18 alternative strategies were identified for Gatiga Snack MSMEs. Since these strategies cannot be implemented simultaneously, prioritization using the QSPM matrix is essential to ensure structured execution. The QSPM enables ranking of strategies based on their TAS values, helping determine the appropriate implementation timeline. For Gatiga Snack MSMEs, the marketing strategy implementation is divided into three periods: the first period (less than one year), the second period (1–3 years), and the third period (3–5 years or more) (Nataliningsih et al., 2018). The prioritized strategies specific to Gatiga Snack MSMEs are shown in Table 4.

Table 4. Marketing Strategy Priorities for Pangas Catfish Fish Skin Chip

Strategy Code	Strategy	TAS	Rank	Period
WO4	Form a special marketing team to manage the Gatiga Snack MSME business.	7.296	1	1st Period
WO2	Intensive promotion by creating a regular schedule of promotional activities both online and offline.	7.141	2	
ST3	Build a brand image by making reviews or testimonials about the quality of Gatiga Snack products so that new consumers will trust and be interested in buying.	7.031	3	
SO1	Expand the marketing area for Gatiga Snack products by utilizing business permits (P-IRT) and halal certificates to increase sales.	7.025	4	
WO5	Improve your ability to read the market to create copywriting on social media	6.900	5	
SO4	Place paid advertisements on social media platforms to increase brand awareness of Gatiga Snack products.	6.885	6	

Strategy Code	Strategy	TAS	Rank	Period
ST1	Offer discounts, cashback and flash sales to attract consumers at e-commerce promotional events.	6.819	7	2nd Period
SO5	Create content that involves interaction between Gatiga Snack and the audience on social media to increase customer engagement and maintain consistency in advertising posts.	6.793	8	
ST4	Maintain the product's price, quality and taste so that it can compete with similar products.	6.700	9	
SO3	Join communities about e-commerce and social media.	6.682	10	
ST2	Improve good service to maintain consumer comfort by providing Gatiga Snack products that are always available.	6.494	11	
SO6	Take advantage of support from the local government by actively participating in the government's MSME activities, such as opening a stand to introduce Gatiga Snack products.	6.441	12	
SO2	Increase and establish collaboration between Gatiga Snack MSME owners and resellers.	6.421	13	3rd Period
WT2	Evaluate the performance of Gatiga Snack MSMEs.	6.317	14	
WT3	Create a mascot identical to the Gatiga Snack MSME to strengthen its identity	6.273	15	
WO1	Added variations in product packaging weight and taste to the Pangas Catfish Skin Chips of Gatiga Snack product	6.178	16	
WO3	Open a private outlet strategically or place it in a gift shop so that Gatiga Snack products are easily accessible to consumers.	5.952	17	
WT1	Create a mascot identical to the Gatiga Snack MSME to strengthen its identity.	5.424	18	

The marketing strategies formulated for Gatiga Snack MSME are structured into three implementation periods based on urgency, feasibility, and business growth projections. Six strategies are prioritized in the first period, intended for implementation within less than a year. These include Form a special marketing team to manage the Gatiga Snack MSME business (WO4) with the highest TAS of 7.296 to handle digital promotion and event participation. Intensive promotion by creating a regular schedule of promotional activities both online and offline (WO2) are also emphasized, involving scheduled online postings and participation in offline bazaars to enhance product visibility. Build a brand image by making reviews or testimonials about the quality of Gatiga Snack products so that new consumers will trust and be interested in buying (ST3) by encouraging customer testimonials aims to increase trust among new consumers. The business is also advised to utilize existing P-IRT and halal certifications (SO1) to expand its market while ensuring these certifications remain valid. Additional strategies include enhancing copywriting skills (WO5) through training to improve communication on digital platforms and using paid social media advertisements (SO4), particularly Instagram Ads, to reach a broader audience and improve brand awareness.

In the second period, which spans one to three years, strategies focus on strengthening consumer engagement and sustaining competitive advantages. These include offering promotional deals such as discounts, vouchers, and flash sales (ST1) to stimulate impulse buying, especially on e-commerce platforms. Gatiga Snack is also encouraged to create interactive content (SO5), like quizzes and giveaways, to boost customer engagement and social media performance. Maintaining consistency in product quality, taste, and pricing (ST4) is vital to retain customer loyalty and compete effectively. Joining e-commerce and social media communities (SO3) supports networking and business learning while providing quality service and maintaining product availability (ST2), essential for enhancing customer satisfaction. Additionally, leveraging government support by participating in MSME-related events (SO6) can increase brand exposure and market access.

The third period, designed for long-term strategies (three to five years or more), involves expanding the business's reach and solidifying its brand identity. Collaborating with resellers (SO2) helps broaden distribution channels, while regular business performance evaluations (WT2) ensure strategic effectiveness and accountability. Developing a brand mascot (WT3) which can seen in Figure 3 adds a visual identity that strengthens brand recall, particularly during events. The selection of the character and colors is based on the business owner's preferences. The yellow Siger symbolizes that Gatiga Snack MSME is located in Lampung, while the orange color and body shape represent enthusiasm. This reflects that the business owner must remain spirited in developing the business.

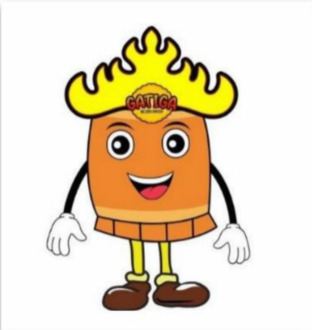

Figure 3. Gatiga Snack MSME's Mascot Recommendation

Adding variations in product packaging weight and taste to the pangas catfish skin chips of Gatiga Snack product (WO1) offers value to consumers and meets diverse market preferences. Establishing a physical retail outlet in a strategic location (WO3) is also recommended to improve product accessibility. Lastly, improving internal marketing management systems (WT1), especially in digital marketing and financial record-keeping, will support the business's sustainable growth and operational efficiency. These strategies collectively guide Gatiga Snack MSME toward improved competitiveness and long-term success.

4. CONCLUSIONS

This study on the making and priority selection of marketing strategies for Gatiga Snack MSMEs concluded that based on a SWOT analysis incorporating marketing mix variables, 18 strategic alternatives were identified. These include 6 Strength–Opportunity (SO) strategies, 4 Strength–Threat (ST) strategies, 5 Weakness–Opportunity (WO) strategies, and 3 Weakness–Threat (WT) strategies. Three implementation periods were established using the Quantitative Strategic Planning Matrix (QSPM). In the first period, six strategies are recommended, with the highest Total Attractiveness Score (TAS) of 7.296 assigned to Forming a special marketing team to manage the Gatiga Snack MSME business (WO4). Six other strategies were proposed in the second period, with the highest TAS of 6.819 for Offer discounts, cashback and flash sales to attract consumers at e-commerce promotional events. (ST1). Six strategies are also recommended in the third period, with the highest TAS of 6.412 assigned to increase and establish collaboration between Gatiga Snack MSME owners and resellers (SO2).

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Characterization of Ready-to-Drink Decaffeinated Coffee Enriched with Lime and Lemon

Nita Kuswardhani*[1], Dania Mazidatul Hana[1], Andi Eko Wiyono[1]
[1]Department of Agroindustrial Technology, Faculty of Agricultural Technology
Universitas Jember Jl. Kalimantan 37, Jember 68121, Indonesia.
Email: nita.ftp@unej.ac.id*

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Abstract
This study aims to determine the physical, chemical, and sensory characteristics of and the appropriate and optimal formulation for producing ready-to-drink (RTD) robusta decaffeinated coffee variations with the addition of lime (citrus aurantifolia) and lemon (citrus limon) juice. The ingredients used for coffee preparation include decaffeinated robusta coffee powder, lemon, lime, sugar, and water. The experimental design used in this study was a completely randomized design (CRD) with three factors and two levels: citrus type (A1: lemon; A2: lime), lemon or lime juice concentration (B1: 5%; B2: 10%), and liquid sugar volume (C1: 15 ml; C2: 25 ml). These factors were designed to create 8 treatments for physical, chemical, and sensory testing. Data analysis was performed statistically using Analysis of Variance (ANOVA) at 5% significance level and further testing with Duncan's Multiple Range Test (DMRT) when any differences were found. The results showed that the interaction of the three factors affected the physical and chemical characteristics of caffeine content, pH, and antioxidant activity. The addition of lime and lemon juice did not have a significant effect on the characteristics of vitamin C content and brightness. Treatment A1B1C2, with the composition of 5 ml lemon juice and 25 ml sugar water, provides the best formulation based on the review of physical, chemical, and sensory characteristics.
Keywords: *Lime, Lemon, Robusta decaffeinated coffee, RTD.*

1. INTRODUCTION

Robusta coffee (Coffea canephora) is favored by Indonesians for its strong flavor and aroma. Moreover, it has a higher caffeine content than arabica coffee. The caffeine content in robusta coffee ranges from 1% to 2% of the total dry weight, higher than in the arabica coffee, which ranges from 0.4% to 2.4% (Budi et al., 2020). The high caffeine content in robusta coffee can have adverse health effects, such as high cholesterol (Krispila et al., 2020), headaches, and sleep disturbances. The decaffeination process can reduce caffeine levels and, thus, reduce health risks for those who are intolerant to caffeine (Br Ginting et al., 2022).

One of the decaffeination methods is soaking. Based on the preliminary research, soaking robusta coffee beans for 3, 5, and 7 days, while replacing its water within 24 hours, can significantly decrease the caffeine content of robusta coffee up to 0.65-0.89% compared to the control sample (1.78%) with the lowest caffeine content in the 7-day soaking treatment(0.65%) (Kuswardhani, 2023).

The innovation of adding lemon (Citrus limon) and lime (Citrus aurantiifolia) to decaf coffee is an interesting innovation as it provides health benefits and flavors (Nascimento et al., 2020). Lemon and lime contain flavonoids, terpenoids, citric acid, and vitamin C that function as antioxidants, anti-inflammatories, and antimicrobials, which can reduce the risk of cardiovascular disease and improve digestive system health. According to Fatin & Azrina (2017), the vitamin C content in lemon 43.96 mg/100g and lime 27.78 mg/100g is higher than some other types of citrus. Residual bitterness from decaf coffee can be masked or balanced by its acidic and citrusy taste. Despite the fact that the caffeine or coffee content is unchanged, this may give the impression that the coffee is milder, fresher, or less strong.

Ready-to-drink (RTD) decaff coffee enriched with lime and lemon juice offers a delicious decaffeinated coffee flavor, designed for consumers who want to enjoy coffee without the effects of

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excessive caffeine. This product is convenient and can be enjoyed anytime. Moreover, it is rarely found in the market, creating a great opportunity for the development of RTD decaf coffee with lime and lemon flavors. Therefore, the combination of decaffeinated robusta coffee with lime and lemon juice results in an innovative, delicious, and healthy RTD. This study aims to determine the physical, chemical, and sensory characteristics, as well as to determine the appropriate and optimal formulation for producing ready-to-drink (RTD) robusta decaffeinated coffee variations with the addition of lime and lemon juice.

2. MATERIAL AND METHODS

2.1 Tools and Materials

2.1.1 Tools

The tools used in this research are analytical scales (Ohaus), filters, pans, measuring cups, stoves, spatulas, bottles, funnels, spoons, pH meter PHS 26C Bench, General colorimeter-AMT 507, erlenmeyers, beakers, volumetric flasks, pipettes, burettes, measuring bottles, stirrers, Spectrophotometer vis 721, vortexes, and test tubes.

2.1.2 Materials

The materials used for making RTD coffee are robusta decaf ground coffee that was made by soaking coffee beans for 7 days, lemon, lime, sugar, and water. The materials used for analysis are buffer solution, distilled water, tissue paper, iodine, amylum indicator, iodine, ascorbic acid, DPPH (2,2- diphenyl-1-picrylhydrazyl), 95% ethanol, distilled water, and calcium carbonate (CaCO3).

2.2 Research Design

This research used the Complete Randomized Design (CRD) technique. The following are the treatment variations applied in this study. The three factors are varied to get optimal results with the following formulation on Table 1:

Factor A: Type of citrus used
A1 : Lemon
A2 : Lime
Factor B: Concentration of lime or lemon juice (%)
B1 : 5% of brewed coffee
B2 : 10% of brewed coffee
Factor C: Liquid sugar (ml)
C1 : 15 ml
C2 : 25 ml

Table 1. Experimental design

Code	Coffee Bean (mL)	Lime Juice (mL)	Lemon Juice (mL)	Sugar Solution (mL)	Water (mL)
A1B1C1	100	0	5	15	100
A1B1C2	100	0	5	25	100
A1B2C1	100	0	10	15	100
A1B2C2	100	0	10	25	100
A2B1C1	100	5	0	15	100
A2B1C2	100	5	0	25	100
A2B2C1	100	10	0	15	100
A2B2C2	100	10	0	25	100

2.3 Research Stages

2.3.1 Making RTD Decaf Coffee with the Addition of Lime and Lemon Juice

The process of making the drink began with brewing decaffeinated coffee grounds, which can be seen in Figure 1.

2.3.2 Physical, Chemical, and Sensory Testing

Hedonic methods were used for conducting sensory tests. The sensory test used 30 untrained panelists (BSN, 2006). Then, physical (pH, lightness) and chemical characteristics (vitamin C, antioxidants, and caffeine) were measured in duplicate.

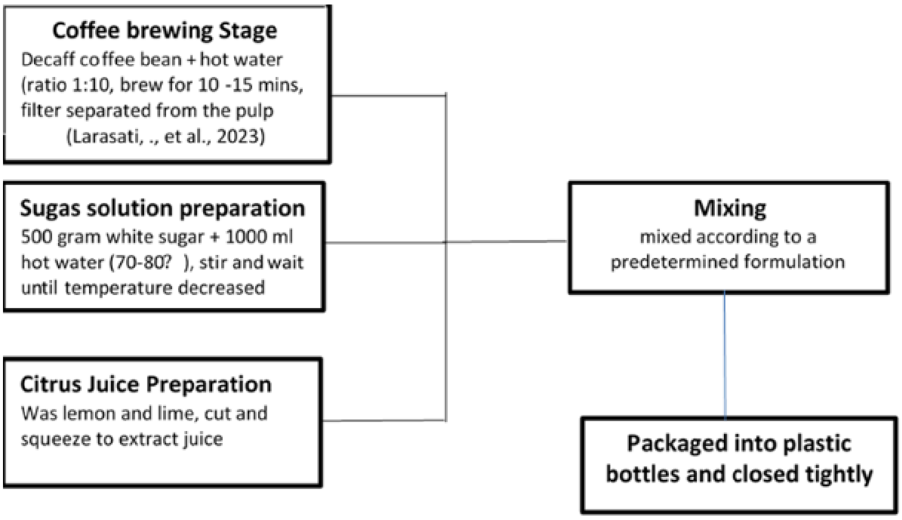

Figure 1. RTD decaf coffee enriched with lime and lemon

2.3.3 Determination of the Best Formulation

The best formulation of RTD decaffeinated coffee with lime and lemon juice was determined by using the exponential comparison method, based on the results of physical and sensory tests. According to Rangkuti (2011), it quantifies the opinion of one or more people on a certain scale. The exponential comparison method steps include:

1. Determination of decision alternatives.
2. Formulation of decision criteria to be assessed.
3. Determination of the relative importance of each criterion with a certain conversion scale.
4. Determination of the relative degree of importance of each decision alternative.
5. Ranking the value of each decision alternative.

The formulation of the Exponential Comparison Method for score calculation was shown as equation 1:

$$Total\,Value\,(TNi) = \sum_{J=1}^{m} (RKij)^{TKKj} \quad (1)$$

Where:

Total value I : Total final value of the i-th alternative
RK_{ij} : Degree of importance of the j-th relative criterion in decision option i
TKK_j : Degree of importance of the j-th relative criterion TKK j > 0
N : Number of decision options
M : Number of decision criteria

2.4 Data Analysis

The data collected were analyzed using the SPSS version 23 program. Physicochemical tests were carried out using the univariate Analysis of Variance (ANOVA) method at the α = 0.05 level to determine differences between treatments. If there was a difference, it was followed by the Duncan

Multiple Range Test (DMRT). Sensory tests were analyzed using the chi-square test at the α = 0.05 level to determine differences in data. The data were presented in the form of bar charts and interpreted descriptively.

3. RESULTS AND DISCUSSION

The physical, chemical, and sensory characteristics of RTD decaffeinated coffee are closely interrelated, as the additional lime and lemon during processing can influence the beverage's color (lightness), pH, caffeine content, antioxidant activity and vitamin C, which in turn affect key sensory attributes such as color, aroma, taste and after taste; thus, understanding these interactions is essential for maintaining product quality and consumer satisfaction on the RTD decaff coffee.

3.1 Physical, Chemical, and Sensory Characteristics of RTD Decaf Coffee Enriched with Lime and Lemon

A. Lightness

Color is an important factor in product acceptance as it is the first sensory property seen by the consumer. Lightness analysis of RTD coffee using a color reader showed the degree of lighness between 76.0-84.8 (where 0 is black and 100 is white). The ANOVA test on the degree of brightness showed that the interaction between the variables (A*B*C) did not have a significant effect (P>0.05). However, the concentration of lime and lemon (factor B) had a significant effect on the degree of lighness. The concentration of lime, lemon, and sugar solution did not significantly change the color of the RTD decaf coffee. Since the ANOVA test results were not significant, further testing with DMRT was not conducted. The results of this test can be seen in Figure 2.

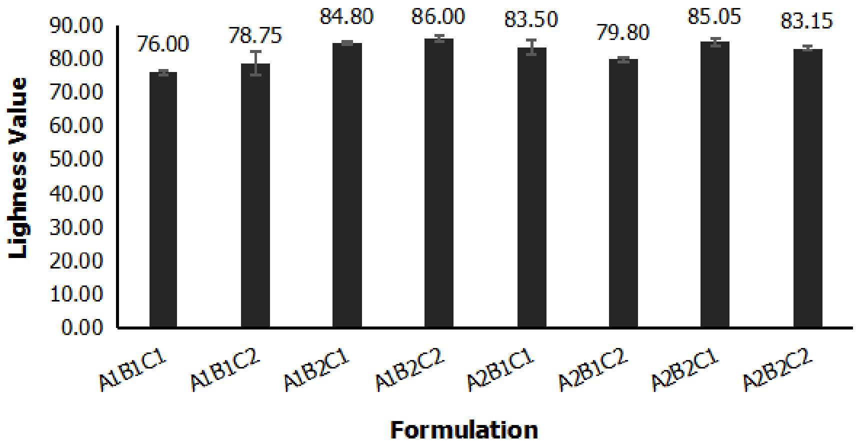

Figure 2. Degree of Brightness of RTD Coffee Drinks

Treatments with the addition of 10 ml lemon juice (A1B2C1 and A1B2C2) and lime juice (A2B2C1 and A2B2C2) produced higher lightness values compared to the addition of 5 ml. The addition of more lemon or lime juice increases the degree of brightness of the coffee drink. The addition of lime and lemon juice to coffee pulp juice drinks produces a bright brown color (Arpi et al., 2018). The more lemon juice used, the more yellow the color of the beverage due to the natural color of the lemon (Geri et.al., 2019).

B. Caffeine

The caffeine content in robusta coffee ranges from 1% to 2% of total dry weight (*Budi* et al., 2020). In this research, caffeine levels in robusta coffee were 1.78 mg/100 mL. Meanwhile, the caffeine level of RTD decaf coffee varied between 0.33-0.74 mg/100 mL. The interaction between lime, lemon, and sugar concentration showed significant differences in caffeine levels. Further tests with DMRT confirmed the significant difference in caffeine levels between treatments. Since Non-decaf RTD coffee products use coffee as the primary source of caffeine, the caffeine content of RTD decaf coffee drinks compared to non-decaf coffee can be seen in Figure 3.

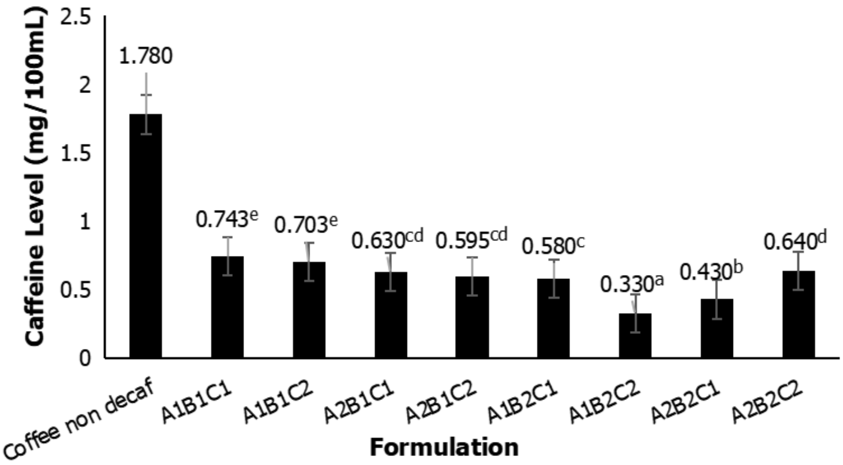

Figure 3. Caffeine Levels of RTD Coffee Drinks

The A1B2C2 and A2B2C1 treatments showed significant differences compared to the other treatments. The addition of lime and lemon affects caffeine levels in coffee drinks, with the higher the concentration of lime and lemon, the lower the caffeine levels. The addition of 5 ml of lime and lemon produced caffeine levels of 0.743-0.595 mg/100 ml, while 10 ml of lime and lemon reduced caffeine levels to 0.640-0.330 mg/100 ml. The flavor was changed by lime and lemon, which lessen bitterness or modify the scent, giving the impression that caffeine's effects are less potent. But the caffeine level remains constant unless water or citrus juice is used to dilute the coffee. The quantity will be increased by adding lemon or lime juice, but the overall caffeine content will remain the same, even if the caffeine concentration per milliliter is reduced. Caffeine's solubility may be somewhat influenced by the acidity of citrus fruits (low pH). The lower the caffeine level, the lower the acidity (pH) of the drink (Aini et.al., 2021).

C. pH

The results showed that the pH of RTD decaf coffee drinks with the addition of lime and lemon ranged from 2.92-3.24. The value of the degree of acidity of RTD coffee drinks can be seen in Figure 4.

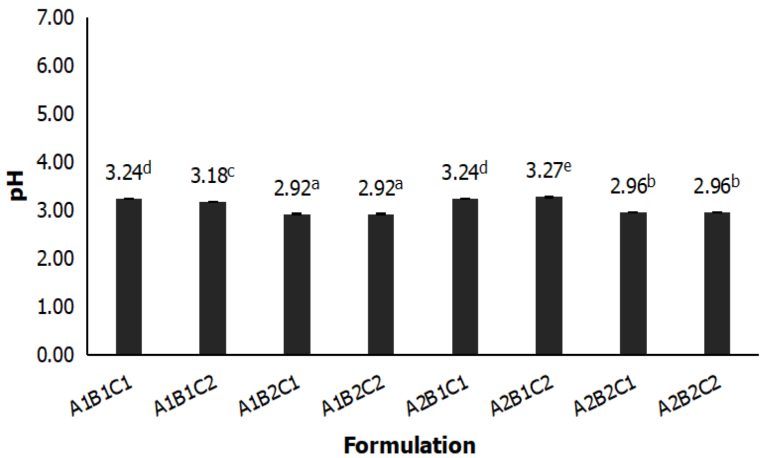

Figure 4. pH of RTD Coffee Drink

ANOVA test results showed that the interaction of the three factors affected the acidity of RTD coffee drinks. DMRT testing confirmed significant differences between treatments. The addition of lime and lemon juice decreased the acidity of the beverage, with a more significant decrease in the addition of lime juice due to the lower pH. The addition of 10 mL of lemon or lime juice showed the lowest pH value. These results are consistent with previous research (Agustin et.al., 2014), which stated that the addition of lemon or lime can reduce the pH of the drink due to an increase in hydrogen ions from ascorbic acid. Therefore, the more citrus juice added, the lower the pH of the RTD coffee drink (Elfrida & Sarjani, 2021).

D. Antioxidant

Antioxidant activity testing on RTD decaf coffee drinks using the DPPH method showed values ranging from 1.44-1.78 mmolTE/100ml. ANOVA test results showed that the interaction between citrus type, citrus concentration, and sugar concentration had a significant effect on antioxidant activity. The antioxidant activity values can be seen in Figure 5.

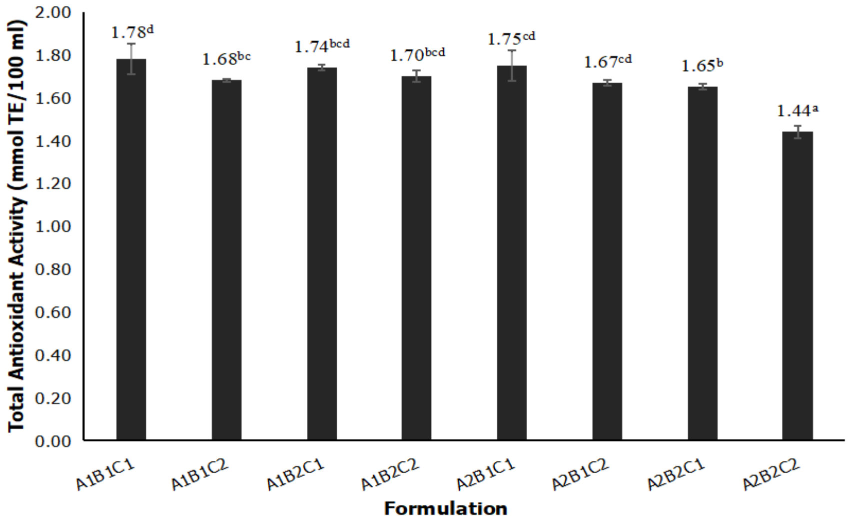

Figure 5. Antioxidant activity of RTD coffee drinks

The results showed that the total antioxidant activity in coffee drinks with the addition of lemon juice ranged from 1.78-1.68 mmol TE/100 ml, while in coffee drinks with the addition of lime juice ranged from 1.75-1.44 mmol TE/100 ml. Lemon has a higher antioxidant activity than lime, in line with previous research findings. The addition of sugar in coffee drinks also affects the antioxidant activity, where the more sugar added, the lower the antioxidant activity level (Permanasari & Aslam, 2021).

E. Vitamin C

The results of the analysis showed that the vitamin C in coffee drinks ranged from 5.13-10.26 mg/100 ml. The interaction between the factors of lime or lemon addition at various compositions did not give statistically significant differences in vitamin C. The vitamin C content of RTD coffee drinks can be seen in Figure 6.

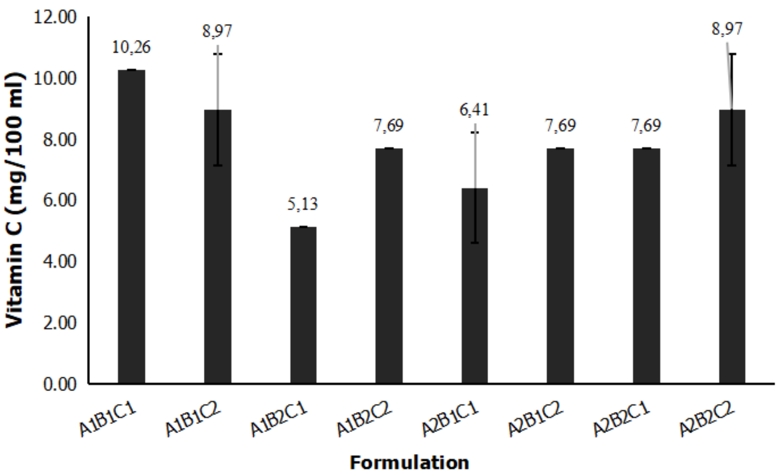

Figure 6. Vitamin C content of RTD coffee drinks

The study showed that the addition of lemon juice resulted in a higher vitamin C content than the addition of lime juice. In comparison to limes, lemons often produce a larger juice yield per 100 grams of fruit and have bigger juice vesicles. Because of its greater juice content, the edible part has more soluble vitamin C. Lemons contain more vitamin C due to otheir unique metabolic characteristics, greater juice yield, and biochemical pathways that promote the production and retention of ascorbic acid (Lee & Kader, 2000; USDA, 2023; Iqbal et al., 2004). In addition, there were differences in vitamin C content between treatments. Factors such as respiration, oxidation and storage processes can also affect vitamin C levels in beverages, including coffee drinks and citrus-based RTDs ((Lee, S. K., & Kader, A. A. ,2000); Davey, M. W., et al.,2000; Bates, R. P., Morris, J. R., & Crandall, P. G., 2001; Ekanayake, S., et al., 2004; Fennema, O. R.,1996).

F. Sensory Characteristics

A panel of thirty untrained individuals used a 5-point scale in a hedonic test to assess the acceptability of RTD decaffeinated coffee with citrus flavor. Under the sensory science literature's advice for early-stage product assessments (Lawless & Heymann, 2010; Stone et al., 2012; ISO 11136:2014), this sample size was determined to be sufficient for preliminary screening with a 95% confidence level. Panelists were asked to rate the color, aroma, taste, and aftertaste attributes on a Likert scale from strongly dislike to strongly like.

1) Color

Color is one of the important aspects in the physical assessment of a food product. As the main visual, color is often the main factor in consumer assessment of a food product (Arifin & Widia Putri, 2020). The total value of panelists' liking for the color of RTD coffee drinks can be seen in Figure 7.

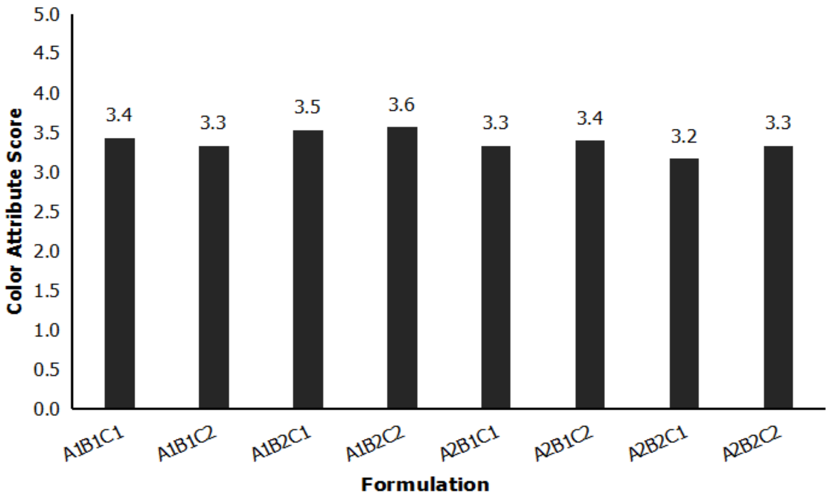

Figure 7. Color Attribute Score

The results showed that the color liking scores of RTD coffee drinks ranged from 3.2-3.6, with panelists showing a neutral reaction. Lemon juice received a slightly higher color rating (3.6-3.3) than lime juice (3.4-3.2). Citrus type had a significant effect on the color rating of the coffee drink, while citrus and sugar concentration had no significant effect. The use of larger amounts of lemon juice, especially 10 ml, tended to give better color ratings, as more lemon juice gave the beverage a more striking yellow color.

2) Aroma

The panelists gave RTD coffee beverage aroma favorability scores ranging from 3.4-2.9, indicating variation in scent ratings. The total value of panelists' liking for the aroma of RTD coffee drinks can be seen in Figure 8.

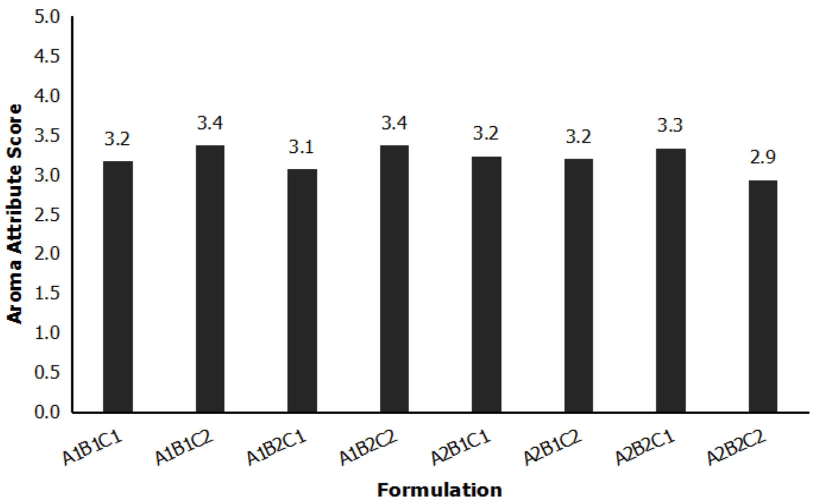

Figure 8. Aroma Attribute Score

The panelists rated the aroma of ready-to-drink coffee beverages with a favorability range between 3.4 (neutral) to 2.9 (dislike), with an average of 3.2 (neutral). The most preferred treatments were A1B1C2 and A1B2C2, with the addition of 5 ml and 10 ml of lemon juice. The least preferred treatment was A2B2C2, with the addition of 10 ml of lime juice, as the strong lime aroma eliminated the coffee scent. Previous studies have shown that the addition of lemon to other beverages can enhance distinctive aroma and reduce less desirable scents. (Oktavia et.al., 2017).

3) Taste

Panelists rated the taste of ready-to-drink coffee with a range of favorability scores between 3.4 and 2.2. The average panelists' liking of the RTD coffee beverage flavor is shown in Figure 9.

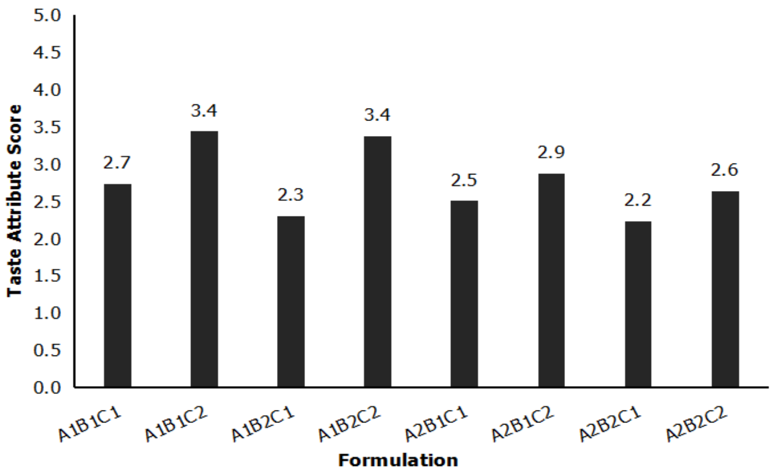

Figure 9. Taste Attribute Score

Treatments A1B1C2 and A1B2C2 scored the highest (3.4), indicating neutral. The addition of 25 ml of sugar, 5 ml of lemon in A1B1C2, and 10 ml of lemon in A1B2C2 made the coffee drink balanced with a strong touch of lemon. However, panelists liked the A1B2C1 and A2B2C1 treatments less due to the addition of less sugar (15 ml) and more citrus (5 ml lemon/lime). The panelists' preference was for lemon over lime in the coffee drink. The lemon provided a more favorable taste, and the addition of sugar helped to create a balance of taste with the sourness and bitterness of the product (Arpi et al., 2018). The addition of orange juice can also enhance the taste of coffee pulp juice drinks, melon juice, and hard candy (Daniela et al., 2022; Valentine et al., 2023; Muzaifa et al., 2022).

4) After Taste

The results of the chi-square test showed significant differences in favorability of aftertaste between treatments in RTD coffee drinks. The factors of lemon and lime addition, along with concentration of added sugar, significantly affected the aftertaste (Likumahua et.al., 2022). However, the concentration of citrus added did not significantly affect the aftertaste. The average panelists' liking of the aftertaste of RTD coffee drinks is shown in Figure 10.

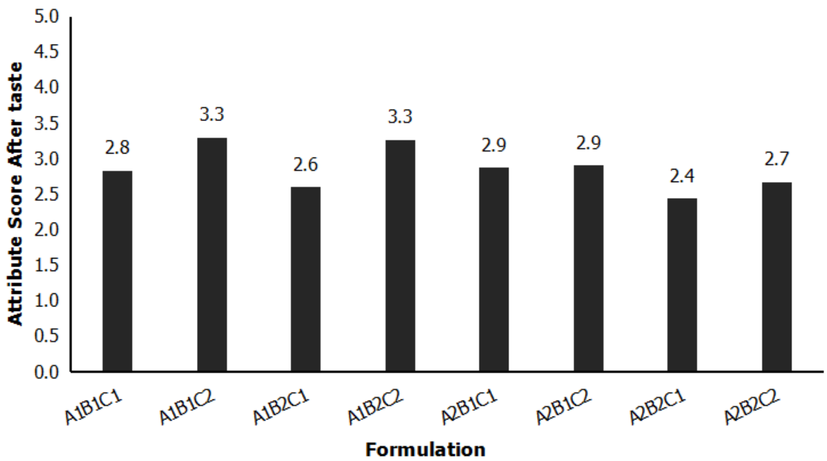

Figure 10. After Taste Attribute Score

The liking for the aftertaste of RTD coffee beverages ranged from neutral to dislike. The level of liking was influenced by the sugar concentration, as the more sugar was added, the higher the level of liking for the aftertaste.

3.1.1 Best Formulation of RTD Coffee Beverage

The first step was to determine the decision alternatives; The Decision Alternatives used were eight formulations or treatments that have been carried out. The second step was to prepare the decision criteria. This study used eight parameters: taste, aroma, color, aftertaste, caffeine, antioxidants, vitamin C, and pH. The third step was to determine the weight of importance of each decision criterion. The determination of the relative importance of each decision criterion were obtained from the results of the interviews with coffee experts (consisting of 5 people, namely coffee researchers, baristas, and trained panelists) are shown in Table 2.

Table 2.The weight of importance of each criterion

No.	Criteria	Weight of important
1	Taste	5
2	Aroma	5
3	Color	4
4	After taste	4
5	Caffeine	3
6	Antioxidants	3
7	Vitamin C	3
8	pH	3

The fourth step was to assess all alternatives on each criterion in the form of a total score for each alternative. The results of the research for all the parameters are shown in Table 3.

Table 3. Result of each parameter

Alternative	Criteria							
	Taste	Aroma	Color	After taste	Caffeine	Antioxidant	Vitamin C	pH
A1B1C1	2,73	3,17	3,43	2,83	0,74	1,78	10,26	3,24
A1B1C2	3,30	3,37	3,53	3,30	0,70	1,68	8,97	3,18
A1B2C1	2,60	3,07	3,10	2,60	0,58	1,74	5,13	2,92
A1B2C2	3,27	3,37	3,57	3,27	0,33	1,70	7,69	2,92
A2B1C1	2,87	3,23	3,33	2,87	0,63	1,75	6,41	3,24
A2B1C2	2,90	3,20	3,40	2,90	0,60	1,67	7,69	3,27
A2B2C1	2,43	3,33	3,17	2,43	0,43	1,65	7,69	2,96
A2B2C2	2,67	2,93	3,33	2,67	0,64	1,44	8,97	2,96

From the table above, the formula with the best analysis results was given a ranking of 1, while the formula with the lowest analysis results was given a ranking of 3, with the criteria that the bigger the better for the parameters of taste, aroma, color, after taste, antioxidant activity, vitamin C and pH, while for the caffeine content parameter; the smaller the better. The fifth step was to calculate the Total Value (TN) of each alternative using equation (1). The example of calculation for each alternative was:

$$A1B1C1 = (2)^5 + (1)^5 + (1)^4 + (2)^4 + (2)^3 + (1)^3 + (1)^3 + (1)^3 = 61$$
$$A1B1C2 = (1)^5 + (1)^5 + (1)^4 + (1)^4 + (2)^3 + (2)^3 + (1)^3 + (1)^3 = 22$$

And the last step was to sort the Total Value (TN) that had been calculated. The greater the alternative Total Value (TN), the higher the priority order or the best formulation. The Exponential Comparison Method result was described in the following Table 4.

Table 4. The Exponential Comparison Method Result

Alterna-tive	Criteria								Decision Value	Rank
	Taste	Aroma	Color	After taste	Caffe-ine	Antioxi-dants	Vitamin C	pH		
A1B1C1	2	1	1	2	2	1	1	1	61	3
A1B1C2	1	1	1	1	2	2	1	1	22	1
A1B2C1	2	1	1	2	1	1	3	2	95	6
A1B2C2	1	1	1	1	1	1	2	2	38	2
A2B1C1	2	1	1	2	2	1	3	1	87	5
A2B1C2	2	1	1	2	2	2	2	1	75	4
A2B2C1	3	1	1	3	1	2	2	2	351	8
A2B2C2	2	2	1	2	2	3	1	2	125	7
Weight of Import-ant	5	5	4	4	3	3	3	3		

The results of the exponential comparison method calculation showed that the selected treatment was A1B1C2, with the lowest total score of 22. This treatment gave an overall good decision criteria score, with no maximum score of 8. Thus, the A1B1C2 formulation, which used 5ml lemon juice and 25ml liquid sugar, is the best combination for RTD robusta decaf coffee drinks.

This selected formulation gave the best results in terms of physical, chemical, and sensory properties. The physical and chemical properties of the best formulation included caffeine 0.70 mg/100 ml; pH 3.18; antioxidant 1.68 mmol TE/100 ml; vitamin C 8.97 mg/100 ml; and color (*L) 78.75. Sensory testing showed good panelist liking scores on the parameters of color (3.53), aroma (3.37), taste (3.43), and aftertaste (3.30).

4. CONCLUSIONS

Based on the research conducted, it was found that the addition of lime and lemon juice to robusta decaf coffee affects the physical and chemical characteristics of caffeine levels, pH, and antioxidant activity. In the characteristics of vitamin C and lightness, the addition of citrus juice does not have a significant effect. Sensory characteristics of taste and aftertaste have a significant effect with the addition of citrus juice, while color and scent do not have a significant effect statistically.

Among the various formulations tested, the treatment A1B1C2 with the composition of 5 ml lemon juice and 25 ml sugar water provides the best formulation in terms of physical, chemical, and sensory properties. The physical and chemical content of the best formulation of RTD coffee is caffeine 0.70; pH 3.18; antioxidant 1.68; Vitamin C 8.97; and color (*L) 78.75. In sensory testing, the panelists' favorite scores were obtained in the parameters of color 3.53, aroma 3.37, taste 3.43, and aftertaste 3.30.

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