International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 6
ISSN: 2088-5334

The Effect of Freeze Drying and Determination of Heat Transfer on Various Maturity Levels of Robusta Coffee Fruits

Tri Hariyadi [a,b,*], Mohamad Djali [c], Bambang Nurhadi [c], Santi Rosniawaty [d]

[a] *Chemical Engineering Department, Politeknik Negeri Bandung, Bandung, 40559, Indonesia.*
[b] *Doctoral Program in Agricultural Sciences, Faculty of Agriculture, Universitas Padjadjaran, Bandung, 40600, Indonesia*
[c] *Department of Food Industrial Technology, Faculty of Food Industrial Technology, Universitas Padjadjaran, Bandung 40600, Indonesia*
[d] *Department of Agriculture Cultivation, Faculty of Agriculture, Universitas Padjadjaran, Bandung, 40600, Indonesia*
*Corresponding author: *tri.hariyadi@polban.ac.id*

***Abstract*— The quality of coffee beans is influenced by the level of maturity, which can be determined based on the skin color of the coffee fruit and post-harvest processing. The study was conducted to determine the effect of freeze-drying on various variations in the level of maturity of water content, caffeine, and heat transfer value. The freeze-drying method was chosen because it can maintain the chemical content of the food. Robusta coffee was obtained from Karawang Regency, West Java, Indonesia. Coffee fruit is sorted by skin color using a colorimeter. Fresh beans are obtained by stripping the fruit skin and epidermis and washing mucus. Fresh bean is reduced in size until it passes the 18-mesh sieve. Freeze-drying is operated at an initial temperature of -20 °C, sublimation temperature of 40 °C, and operating pressure of 1 to 6 mbar abs. Water content analysis using gravimetric methods, caffeine content analysis using UV-Vis spectrophotometry method, and fat content using the Soxhlet method. The total heat transfer value is determined from the cup to the material. The results showed that the freeze-drying process at semi-ripe to over-ripe maturity levels could reduce the water content to the permissible limit but cannot be used for unripe. The results of the statistical significance test show that the freeze-drying process at various maturity levels can significantly reduce the water content but can maintain the caffeine content in *robusta* coffee beans. The highest heat transfer value occurs at the un-ripe maturity level of 86.50 *kJoule*.**

***Keywords*— Caffeine; freeze-drying; heat transfer; maturity level; *robusta* coffee.**

Manuscript received 16 Mar. 2021; revised 27 Aug. 2021; accepted 29 Sep. 2021. Date of publication 31 Dec. 2022.

I. INTRODUCTION

Climate change has resulted in various environmental changes, such as temperature, drought, and increased CO_2, that affect plant growth and the final quality of agricultural and food products [1], [2]. With a high demand for climate-resilient products, genetic improvement is considered a key approach in adapting plants to environmental change [3]. Recent concerns about the extinction of wild species due to climate change further emphasize the importance of understanding the genetic and environmental basis of product quality, as wild species are essential genetic resources for sustainable production and improvement of quality [4].

Coffee fruit, often called wet coffee, yields a moisture content of between 60 to 65%. Coffee beans are protected by fruit skin, flesh, mucous layer, horn skin, and epidermis [5]. According to Krishnan [5], the anatomical structure of coffee fruit is divided into two parts, namely the pericarp and seed. Pericarp becomes the outermost part of the coffee fruit, which has three layers. The first layer is called the exocarp, which is the outer layer of the coffee fruit formed by a single layer of dense parenchymal cells. The next layer is called mesocarp, called mucilage, which is the mucus-shaped part of the coffee fruit. The last layer is called the endocarp, the innermost layer of the coffee skin and cover covering the coffee beans. This endocarp part hardens during the ripening of the coffee fruit, thus limiting the final size of the coffee beans inside. The seed consists of the epidermis in coffee, also called perisperm, an outer layer that encloses the seeds and endosperm representing coffee beans' taste. Chemical compounds in the endosperm are caffeine, trigonelline, fat, some proteins, minerals, and lipids [6].

The study by Cheng et al. [7] reveals that the lower canopy produced high-quality coffee beans with a more intense coffee aroma (improvement in organoleptic coffee quality) associated with improved sucrose, trigonelline, and caffeine accumulation in the bean. Starting from a higher maturity stage, beans in the lower canopy had a longer maturity, possibly controlled by growth and photosynthesis genes at the green stage to delay growth, reduce photosynthesis loss at the yellow stage and extend growth at the red stage. However, beans from the upper canopy grew rapidly from a lower maturity level at the green stage with elevated chlorophyll formation and carbon and energy consumption. According to Krishnan [5], Arabica and Robusta coffee have different characteristics, partly because of differences in the level of maturity, taste, aroma, chemical aspects, different economic values, and the ideal climate for the coffee to grow.

Arabica coffee plant growth requirements are at an altitude between 750 to 1500 masl with a temperature of 15 to 18 °C and *robusta* coffee at an altitude between 400 to 1000 masl with a temperature of 18 to 24 °C. Robusta coffee plants are more resistant to pests and have mild requirements for growth, and high productivity, so that starting in 1900, Robusta coffee species developed faster than Arabica coffee types [5]. The term *robusta* is taken from the English word "robust," which means strong. The point is that coffee drinks from Robusta coffee beans have stronger and bitter taste than those from Arabica coffee beans. Robusta coffee is usually used for raw materials of instant coffee and mixing ingredients of blended coffee. Robusta coffee production globally ranks second after Arabica coffee production.

In Indonesia, *robusta* coffee production occupies the first position, while the rest is occupied by producing arabica coffee, *liberica* coffee, and *excelsa* coffee. The Robusta Gayo has more burnt, woody, and earthy notes, whereas the Arabica Kerinci produces higher citrus, acidic and sweet-related characters. Robusta coffee plant has a root system that is not deep, so to be able to grow requires soil that has a high content of organic compounds. This condition causes *robusta* coffee plants to be more suitable to be planted in low-lying areas so that their growth is maximal and is more resistant to rust. Robusta coffee fruit is smaller than Arabica coffee fruit and has a rounded seed shape. Robusta coffee fruit is green when young and turns red when ripe[8]–[10].

Selective harvesting produced beans with high raw quality of all attributes in both washed and unwashed coffee. Natural sundried coffee on raised mesh wire produced high raw bean quality with the lowest primary and secondary defects, followed by coffee dried on a plastic sheet ground floor. Moreover, drying coffee on bare ground highly reduces raw, abnormal color, and unpleasant odor [11].

To get good quality coffee, paying attention to several factors, namely land, altitude, soil fertility, land slope, rainfall, air temperature, air humidity, and solar radiation, is necessary. Good soil conditions for coffee plants have criteria including soil slope of less than 30%, effective soil depth of more than 100 cm, clay texture with crumb topsoil structure, organic matter content greater than 3.5%, or content carbon (C) greater than 2%, soil acidity (pH) 5.5-6.5, and nutrient levels of N, P, K, Ca, Mg from sufficient to high, exposure to high temperature in the last stages of fruit maturation did not strongly depreciate bean quality, under the conditions of unrestricted water supply and moderate irradiance [12].

A. *Coffee Maturity Level*

According to Martinez et al. [13], coffee has four levels of maturity that can be visually distinguished through color, namely:

1) Unripe (Green): Green coffee fruit shows the condition of fruits that are still very young, and when picked, coffee beans are still black, pale white, and wrinkled, and the resulting aroma is weak. The taste obtained is also defective, including grassy, bitter, and very high astringency, so green coffee fruit is not recommended for picking.

2) Semi-ripe (Yellow/Yellowish Green): Yellow coffee/ yellowish green will produce coffee beans with the color of coffee beans gray to pale green. The aroma of coffee fruit produced is weak, and there are defects in taste, including grassy, bitter, and high astringency, so yellow/green coffee beans are not recommended for picking.

3) Ripe (Red): Fresh red coffee fruit and healthy indicates that the fruit is ripe enough, physically grayish beans with a good aroma and taste, balanced acidity, medium bitterness, medium astringency, and there are no defects in the taste, so the coffee fruit with this color recommended being picked.

4) Overripe (Dark Red): Dark red coffee fruit indicates that the fruit is too ripe and will rot. Coffee beans are brown and black with a mild aroma and acidity. There are defects in flavors such as earthy, moldy, and stink.

The maturity level of coffee fruit based on color can be done using the RGB Colorimeter [11], [14]. The measurement system used is the CIE-*L*a*b** or CIELAB system. The CIELAB color system is a scale of colors that is uniform in color dimensions. CIELAB is a color model designed to resemble the perception of human vision using three components, namely L as luminance and a and b as opposite color dimensions. CIELAB provides a view and meaning of each dimension formed, namely the amount of CIE-L* to describe the brightness of colors, where the number 0 is for black and the number 100 for white. The CIE-a* dimension describes the type of green-red color, where the negative number a* indicates green, and the positive number a* indicates red. The CIE-b* dimension is for the type of blue-yellow, where the negative number b* indicates blue and the positive number b* indicates yellow.

B. *Drying*

Drying is the separation of water from food containing small amounts of water by flowing hot air into the water on the surface of food so that there is a reduction in water content in food / a decrease in value aw. The smaller the value of a_w, the longer the shelf life of food products because spoilage microbes cannot grow. According to Wahyuni et al. [15], the value of a_w in *robusta* coffee fruit is ≥ 0.98 because it is included in fresh fruit a_w value of *robusta* coffee beans after the drying process <0.6 with a maximum allowable water content of 7%.

The different drying techniques: i.e., room temperature drying (RTD), solar drying (SD), heat pump drying (HPD), hot air drying (HAD), and freeze drying (FD), were applied to investigate the effect on bioactive components, fatty acid composition, and volatile profile of green coffee beans [11] and had a marked effect on pH, TA, TS, and TSS [16].

According to Elmas [17], low drying temperatures and air velocities caused the product particle size to be lower, resulting in high bulk density than the dried sample at high temperatures. As expected, it has been noted that high drying temperatures caused lower total phenolic content of the product.

Various drying methods can do impairment in the value of aw in food. In general, the term food drying is carried out through sun drying, i.e., the water content of the food is moved to sunlight without the process of controlling the drying temperature and relative humidity. Fruits that will be dried by sun drying are done by blanching first to prevent browning reactions and deactivating enzymes [15]. In addition to using sunlight, drying can be done by freeze-drying/lyophilization methods.

Indonesian people's plantations use a drying process to process coffee for consumption. High temperatures in drying can damage the nutritional content or organic substances in coffee beans because the characteristics of organic substances in food can be denatured at temperatures above 70 to 80 °C. To avoid damaging these organic substances, drying is carried out by freezing drying methods with temperatures below the triple point of water. The freeze-drying process's purpose is to ensure that the food material does not experience denaturation or other damage and that the nutritional quality is still well maintained [18], [19].

C. Freeze Drying

Freeze drying also has a complete drying rate compared to normal drying, which consists of primary drying and secondary drying, so that the resulting product does not cause a wrinkled surface, is more porous, has a lower density, is easy to refresh, normal color, flavor quality, and nutritional value can be maintained [20]. Freeze drying is a drying method where the process is carried out below the triple point of water (temperature 0 °C, pressure 0.00612 atm) so that the water contained in the material freezes and the mass transfer process occurs without undergoing a process of changing the water phase from solid to liquid, but rather directly from the solid phase directly into the vapor phase (sublime) [21].

Over the years, many innovations have been absorbed into the freeze-drying process to render it more beneficial for obtaining superior product quality. The spray-freeze-dried soluble coffee showed better aroma by retaining the characteristic low-boiling aromatic compounds of coffee. In addition, the product also demonstrated other merits such as porous microstructure, instantaneous solubility, good flow characteristics, and high bulk density conferring good packaging and transportation characteristics [22]. Freeze-drying is widely used to dehydrate plant-based foods, including fruits, vegetables, spices, and even some nontraditional foods [22]. Despite the long processing time and being an expensive drying method, it is preferred for the high final quality [20]. For color appeals, drying with low ambient temperature, humidity, and oxygen levels, such as with freeze-drying techniques, would be preferable for retaining bioactive compound levels is a major concern [23]. The FD method was observed most efficient drying method for retaining capsaicin content over other drying methods: i.e., sun drying (SD), hot air drying (HD), microwave-vacuum drying (MVD) [24].

Freeze drying consists of three stages: freezing, primary, and secondary. In the freezing stage, fresh raw materials have a fairly high-water content of 90 to 95%. The primary drying process will reduce the water content in the material until the water content becomes 5 to 10%. Then in the secondary drying, the product will produce a water content of 1 to 2% only [25].

The stages of the freeze-drying process go through several stages; namely, the freezing process in a frozen dryer occurs in a vacuum, where the pressure reduction process will be followed by the evaporation of water vapor from the surface of the food [16]. Latent heat evaporation will require a large amount of energy so it will cause a decrease in the temperature of the material [25]. The freezing process is carried out by putting food into the freezer at minus 40°C. At this temperature, food will freeze quickly, and frozen products will be produced that will not damage the texture. The freezing speed factor is the main factor of the freezing process that will affect the quality of the freeze-dried products produced. The freezing process can be divided into fast freezing and slow freezing. Rapid freezing is usually carried out at very low temperatures to around minus 40 °C, so the freezing process only requires a little time. Conversely, slow freezing is carried out at temperatures above minus 24 °C [20].

The next stage is the primary drying process, which removes water from a frozen solution contained in the food that will be dried through the sublimation process. Sublimation causes the liquid part of the frozen food to change phase directly into a gas [25]. Process conditions (pressure & temperature) must be kept below the triple point of water to ensure that the sublimation process and the melting process do not occur [20]. During primary drying, the pressure is lowered to <1 $T_{orr,}$ and the freeze-drying chamber temperature is raised to cause a sublimation process. During this time, 90% of the water that has been frozen will be sublimated. The water vapor produced during the drying process is then sucked and condensed, so it does not wet the product being dried. The last stage is secondary drying, a continuation of primary drying aimed at reducing the remaining water content to near the desired water level. In this secondary drying process, only a little frozen water is evaporated because most of the water content has been evaporated in primary drying [25].

The things that can affect the efficiency of freeze-drying performance are the characteristics of the material being dried and the operating conditions that are appropriate for the material because the operating conditions and operating time are certainly different for each type of material. Drying solid material takes between 8 to 14 hours [21].

D. Heat transfer in Freeze-drying

As with other drying processes, the freeze-drying process also undergoes heat transfer. Heat transfer in freeze-drying consists of convection, conduction, and radiation heat transfer. Convection heat transfer in the freeze-drying process is included in natural convection with the value of the heat transfer coefficient can be determined using the equation below:

$$N_{Nu} = \frac{hL}{k} = a(N_{Gr} - N_{Pr})^m \quad (1)$$

Where:

$$N_{Gr} = \frac{L^3 \rho^2 g \beta \Delta}{\mu^2} \quad (2)$$

$$N_{Pr} = \frac{C_p \mu}{k} \quad (3)$$

Grashof numbers are interpreted as dimensionless numbers representing the buoyancy ratio to viscosity in free convection, which is similar to the Reynolds number for forced convection. From the equation above, the constants a and m are adjusted to the dimensions of the available tool. After knowing the value of air connectivity using equation 1, in the freeze-drying process, it is necessary to know which heat transfer is more dominant by determining the *Biot* number expressed in the equation:

$$N_{Bi} = \frac{h x_1}{k} \quad (4)$$

If the *Biot* number is <1 then convection heat transfer can be calculated by the equation:

$$Q = C_p \, x \, \rho \, x \, V \, x \, (T_{udara} - T_{bahan}) - \left(1 - e^{-\left(h \frac{A}{C_p \, \rho V} t\right)}\right) \quad (5)$$

If the *Biot* number is 0.1 <NBi <40, then the equation can calculate convection heat transfer:

$$T = T_a + (T_i - T_a) \sum_{n=0}^{\infty} \frac{[2(-1)^n] \, e^{-\lambda_n^2 \alpha t / d_c^2}}{\lambda_n} \cos(\lambda_n \, x / d_c) \quad (6)$$

Conduction heat transfer that occurs in freeze-drying follows the equation of Fourier's Law, namely:

$$\frac{q_x}{A} = -k \frac{dT}{dx} \quad (7)$$

q_x/A commonly known as flux, the minus sign (-) is needed to adjust the direction of displacement, and the value of the thermal conductivity coefficient (k) varies and is affected by temperature.

The general equation for calculating radiation heat transfer from a perfect black material with an emissivity value of ε<1 is as follows:

$$q = A \sigma T^4 \quad (8)$$

Meanwhile, for a material that is not completely black with an emissivity value of ε<1 equation to calculate the heat transfer is as follows:

$$q = A \varepsilon \sigma T^4 \quad (9)$$

Because the emissivity and absorptivity of a material are the same at the same temperature, the emissivity and absorptivity are low for the surface of the metal to be coated and high for the surface of the oxidized metal.

II. MATERIAL AND METHOD

The main raw material is coffee obtained from one of the coffee plantations in the Karawang regency at four variations in the level of maturity with a weight of 1,000 g each. The process of preparing raw materials is done by sorting the harvested coffee fruit into four levels of maturity manually in the coffee garden and using the Amtast AMT567 handheld colorimeter in the Food Technology Laboratory, Chemical Engineering Department, Politeknik Negeri Bandung, Indonesia, based on the skin color of the coffee fruit. Green coffee denotes un-ripe, yellowish-red coffee denotes semi-ripe, full red coffee denotes ripe, and dark red purplish coffee denotes over-ripe. The color measurement model in the colorimeter is the CIE-L*a*b* model that uses three components, L^* as luminance or lighting and a^* and b^* as opposite color dimensions. Determination of the standard value for the measurement of Robusta coffee samples taken based on fruit with a uniform color on each side of the coffee fruit. The sample is measured with the same conditions as the standard that has been determined using a tolerance of 5% because, statistically, the value of 5% explains the level of difference in the value of the sample with a predetermined standard.

The process of stripping fresh coffee is done manually. Robusta coffee beans are then washed using water to remove the remaining mucus and then drained dry. The process of reducing the size of coffee beans using a grinder to pass 18 mesh or 1 mm sieve, then for the freeze-drying process is stored in the freezer at a temperature of 4.6 °C. The total weight of coffee beans obtained after material preparation is 200g/maturity level from the initial coffee fruit weight of 1000g/maturity level.

Some of the reduced coffee beans have been analyzed for water content and chemical compounds in the form of caffeine and fat at the Analytical Instrumentation Laboratory, Chemical Engineering Department, Bandung State Polytechnic, and the rest are put in the freezer for 10 hours for the freezing process.

The freeze-drying process of Robusta coffee beans is carried out at a temperature of -20 °C. The freeze dryer plate temperature is 4.6 °C; 6 mbar abs pressure and heating process until the plate temperature reaches 40 °C [26], against the four levels of fruit maturity, namely un-ripe, semi-ripe, ripe, and over-ripe. The freeze-dried product is put into a zip pack and then coated with aluminum foil and stored in a desiccator to keep the product from quickly absorbing moisture in the air. The tool used in this process is the Freeze-Drying Pilot Plant Model LFZ / EV (Elettronica Veneta, Italy) at the Food Technology Laboratory, Chemical Engineering Department, Politeknik Negeri Bandung. The freeze-dried product is analyzed using the gravimetry method and the content of chemical compounds in the form of caffeine using the UV-Vis spectrophotometry method and fat using the Soxhlet method at the Analytical Instrumentation Laboratory, Department of Chemical Engineering, Politeknik Negeri Bandung, Indonesia.

The results were obtained in the form of analysis of water content and chemical content of raw materials and products resulting from freeze-drying of coffee beans at various levels of maturity, calculating heat transfer during the freezing process of *robusta* coffee beans, and determining the level of statistical significance using the One-Sample t-Test for various changes.

III. RESULTS AND DISCUSSION

A. Determination of the Level of Maturity and Measurement of the Quality of Raw Materials

The process of determining the level of coffee maturity is carried out in four stages: the picking process, the sorting process based on the level of maturity, the process of sorting the quality of coffee, and the process of stripping Robusta coffee. Harvesting is done by picking Robusta coffee beans manually and then grouping them into four levels of maturity based on the skin color of the coffee fruit: unripe, semi-ripe, ripe, and over-ripe [27], [28]. The results of color measurements of *robusta* coffee fruit skin samples are presented in Table I.

TABLE I
CIE-*L*a*b** VALUES AND COFFEE FRUIT CONTENTS

Maturity Level	CIELAB Value			Coffee Fruit Content (%)		
	L*	***a****	***b****	**Water**	**Caffeine**	**Fat**
Un-ripe	39.09	-4.87	27.87	67.35	1.495	10.0
Semi-ripe	44.92	8.36	27.35	51.31	1.349	4.0
Ripe	30.05	20.33	11.26	52.65	1.402	8.0
Over-ripe	19.64	5.86	4.23	50.05	1.720	10.0

Coffee fruit that has been separated based on the level of maturity is then sorted by placing it in a large container filled with water. Drowning coffee fruit indicates that the coffee beans inside are of good quality that are ready to be processed for the drying process, while those that float indicate that the coffee beans are of poor quality or damaged and must be discarded. The coffee fruit, which is selected as raw material, is then subjected to preliminary processing in the form of stripping the outer skin, cleaning the mucus, and reducing its size so that it passes the 18 mesh (1mm) sieve. The raw materials are analyzed for water content, caffeine, and fat, as presented in Table I. The analysis results show that the level of unripe maturity has the highest water content of 67.35%, decreased due to fruit maturity. The water content of coffee beans decreases according to the level of bean maturity [20]. The analysis results show that the level of unripe maturity has the highest water content of 67.35%, while for other levels of maturity, it is relatively the same, between 50.05% to 52.65%.

B. Freeze Drying at Various Levels of Maturity

The drying process using the freeze-drying method is carried out at four levels of maturity, namely un-ripe, semi-ripe, ripe, and over-ripe. From Figure 1 it is known that the freeze-drying time at each maturity level varies, with the highest time at the ripeness level. The difference in the duration of the drying process is caused by differences in pressure during the process, causing the pressure values used for each process to be different. Coffee beans' water content affects thermal conductivity, i.e., the higher the water content, the higher the thermal conductivity coefficient value [15]. The value of heat transfer for the drying process of each level of maturity is different, as presented in Table II.

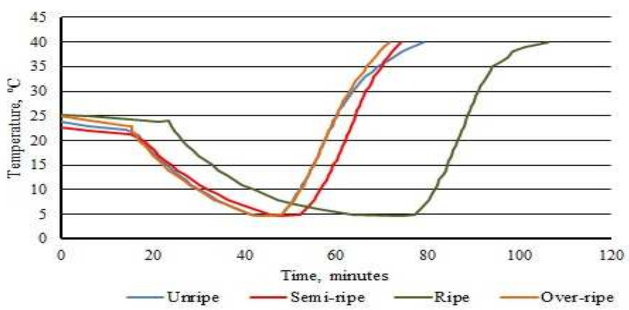

Fig. 1 Drying curves at various maturity levels of *robusta* coffee beans

Table II explains that the value of energy that was successfully transferred by conduction, convection, and radiation to the highest material was at the un-ripe maturity level of 86,504.15 *Joules*, because at the level of unripe maturity, the water content in the seeds is quite high, which is 67.35%. For the level of semi-ripe to over-ripe maturity, the heat value that was successfully transferred to the material is not much different because the water content owned by the maturity level of the coffee is about the same range, which is 50 to 52%.

TABLE II
HEAT TRANSFER VALUES

Maturity Level	Heat transfer values (Joule)			
	Convection	**Conduction**	**Radiation**	**Total**
Un-ripe	1,211.85	85,035.06	257.24	86,504.15
Semi-ripe	840.92	46,788.29	182.56	47,811.77
Ripe	835.08	45,334.60	174.26	46,343.93
Over-ripe	871.81	47,820.35	190.86	48,883.01

C. Changes in Water Content Due to the Freeze-Drying Process at Various Levels of Robusta Coffee Maturity

Water content is the percentage of water content in a material that can be expressed based on wet weight (wet basis) or dry weight (dry basis). Drying is a method for removing part of the water content from a material by evaporating the water it contains by using heat energy to reach the desired water content. The water content of foodstuffs is generally reduced to the extent that microbes cannot grow anymore in them. Coffee bean water content tends to decrease when the temperature and roasting time increase because the greater the temperature difference between the heating medium and the material, the faster the heat transfers to the material and the faster the evaporation of water from the material [15].

The process of drying foodstuffs is carried out as an effort to preserve these foodstuffs. The higher the water content of food, the higher the water activity (aw) value which accelerates the damage to food due to microbial activity. The drying process aims to reduce the water content in the foodstuff to the extent that the moisture content of microbes cannot live in it.

Table III shows that the water content of fresh *robusta* coffee beans has fairly large water content, which is around 50 to 70%. Fresh *robusta* coffee beans have a value of aw> 0.95. At these water levels, microbes that can be active include bacteria such as Vibrio cholera O1 and Escherichia coli, fungi, and mold [21]. The water content of Robusta coffee beans after the freeze-drying process at the level of semi-ripe to over-ripe is 3 to 5%, and the unripe maturity level is 12%. Robusta coffee beans from the drying process have a value of aw <0.6. At this water level, no more microbes can move or grow, so they have a longer shelf life.

Based on this, it can be seen that the freeze-drying process is suitable for drying Robusta coffee beans from semi-ripe to over-ripe maturity levels because it can reduce the water content of ingredients to the minimum allowable limit (7%), while the freeze-drying process is not suitable for drying Robusta coffee beans un-ripe maturity level because it cannot reduce the water content of the material to the required minimum limit (7%) so that another drying method is needed for the process of drying Robusta coffee beans that un-ripe maturity level.

D. Changes in Caffeine Levels Due to the Freeze-Drying Process at Various Levels of Robusta Coffee Maturity

Caffeine is one alkaloid compound contained in tea leaves, coffee beans, and cocoa beans. The function of caffeine in plants is as a natural pesticide that can paralyze and kill pests. This substance is produced exclusively in leaves, nuts, and fruits. Meanwhile, consuming caffeine in humans can have positive and negative effects. A low amount of caffeine will increase alertness, focus, and treat liver cirrhosis. High and acute amounts of caffeine consumption will cause insomnia and trigger excessive mineral excretion. Caffeine consumption, in the long run, will cause the negative effects of caffeine to disappear because of the adaptation of the metabolism system in the body [21]. Consumption of methylxanthine or caffeine must be limited every day. In coffee plants, caffeine is found in almost all parts of the coffee fruit. The process of caffeine formation occurs in the leaves or the outside of the fruit. When the fruit grows, caffeine will be transported to other parts of the fruit. Caffeine levels in coffee beans depend on the species of the coffee fruit itself [29].

Caffeine content is determined to determine the effect of the freeze-drying process on the caffeine content in *robusta* coffee beans. Table III shows the caffeine levels in fresh *robusta* coffee beans, which are 1.3 to 1.7%. While the caffeine content in *robusta* coffee beans after the freeze-drying process is in the range of 0.7 to 1.0%.

Overall, the caffeine content of Robusta coffee beans decreased after freezing. The decrease in caffeine levels indicated the presence of other alkaloid compounds with caffeine-like properties that were dissolved during the extraction process before the freeze-drying process, then the alkaloid compounds were decomposed into other compounds during the freeze-drying process so that they are no longer detected as caffeine, so purity testing of the extract of caffeine obtained is necessary.

E. Changes in fat content due to the freeze-drying process at various levels of Robusta coffee maturity

Fats are compounds that makeup is living cells containing elements C, H, and O, which are stable when heated [2]. Fats can be divided into saturated fats and unsaturated fats based on their chemical structure. Unsaturated fatty acids are fatty acids whose hydrocarbon chains have double bonds. Unsaturated fats are usually liquid at room temperature. Examples of unsaturated fats include vegetable oils and fats found in seeds. Saturated fatty acids are those whose hydrocarbon chains do not have double bonds. Saturated fats are usually solid at room temperature. In coffee beans, fat is mostly contained in the coffee beans in the form of oil, while the outside contains only a small amount of fat in the form of wax. Coffee oil contains triglycerides (fats), phospholipids, tocopherol sterols, diterpenes, and other ester compounds. The average coffee bean has a fat content of between 7 to 17%, wherein Arabica coffee beans' content reaches 15% and in *robusta* coffee beans by 10%. Fat in coffee is a carrier of vitamins and plays an important role in giving a distinctive taste when consumed [16], [30]–[32].

Fat content is determined to determine the effect of the freeze-drying process on fat content in Robusta coffee beans. Table III shows that fresh robusta coffee beans have a fat content of 4 to 10%, while *robusta* coffee beans after freeze-drying have a fat content of 3 to 10%.

TABLE III
ROBUSTA COFFEE CHARACTERISTICS

Maturity Level	Fresh Bean	Product	Change
Water content (%)			
Un-ripe	67.35	12.02	82.15
Semi-ripe	51.31	3.11	93.94
Ripe	52.65	5.17	90.19
Over-ripe	50.05	5.26	89.49
Caffeine content (%)			
Un-ripe	1.495	1.008	32.57
Semi-ripe	1.349	0.763	43.44
Ripe	1.402	0.833	40.58
Over-ripe	1.720	0.744	56.74
Fat content (%)			
Un-ripe	10.0	3.04	69.60
Semi-ripe	4.0	6.57	64.25
Ripe	8.0	6.50	18.75
Over-ripe	10.0	9.91	0.90

Fat is a compound that tends to be stable when heated, so it will not change in amount after drying [11]. Meanwhile, Table V shows a decrease in fat content at the level of unripe, ripe, and over-ripe maturity. And an increase in fat content in the semi-ripe maturity level. Because the fluctuating fat content of robusta coffee beans needs to be tested for the purity of fat so that the specific types of fat in robusta coffee beans are known.

F. Significance level using the One-Sample t-Test method

Based on the results of statistical calculations using the One-Sample t-Test method, the fresh robusta coffee beans and the results of freeze-drying at various levels of maturity value of water content, caffeine content, and fat content do not have significant differences because the t_{count} value is smaller than the t_{table} value of 3.182. The freeze-drying process can significantly reduce water content in robusta coffee beans because the tcount of 21.749 is greater than the ttable of 3.182, while the caffeine and fat content do not have significant differences because the t_{count} is smaller than the t_{table} value of 3.182. Changes in caffeine levels and insignificant fat levels indicate that the freeze-drying process can maintain the caffeine and fat content in *robusta* coffee beans.

IV. CONCLUSION

Water content in coffee beans affects the heat transfer value, i.e., the higher the water content in the material, the higher the conductivity value will be, causing the heat to move toward the higher material. The highest heat transfer value occurs at the un-ripe maturity level of 86,504.15 Joules. The freeze-drying process is suitable for drying Robusta coffee beans from semi-ripe to over-ripe maturity levels because it can reduce the water content of ingredients to the minimum allowable level (7%) but is not suitable for use in unripe maturity levels. After all, it cannot reduce the water content of the material up to the minimum required. Caffeine levels and fat content of fresh *robusta* coffee beans and freeze-drying results at various maturity levels do not have significant differences but can reduce water content significantly. The freeze-drying process can maintain caffeine and fat content in Robusta coffee beans.

ACKNOWLEDGMENT

The author would like to acknowledge Politeknik Negeri Bandung for its contribution to the research funding.

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