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# THE EFFECT OF TEMPERATURE AND ROASTING TIME ON CHANGES IN THE CHARACTERISTICS AND PHYSICAL PROPERTIES OF SOLOK ARABIKA COFFEE BEANS

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**ABSTRACT**

High-temperature coffee roasting is a key initiator of the degradation of complex compounds in coffee beans, ultimately producing the desired taste and aroma for coffee enthusiasts. The aim of this research is to explore the influence of temperature and roasting duration on the changes in the mechanical properties of coffee beans using the conduction heat method. In this study, 500 grams of dried Arabica coffee with an initial moisture content of 12% were placed in a roasting apparatus equipped with a roasting machine. The heat source used was a gas stove, where the surface temperature of the roasting chamber was kept constant through a thermocouple temperature measuring device. The roasting process was carried out for 15 minutes at surface temperatures of 160°C, 180°C, 200°C, and 220°C, respectively. The final moisture content for each surface temperature was 3.72%, 3.65%, 2.13%, and 1.81%. Identification of the degree of roasting was conducted through the evaluation of the physical properties of coffee beans, including color, weight loss, moisture content, texture, and bean density. The decrease in hardness and density could be modeled using kinetic equations, while the color change was indicated by a decrease in the L, a, and b values. The research results confirm that roasting temperature significantly impacts the changes in the mechanical properties of coffee beans. The minimum temperature required to achieve satisfactory roasting levels is 180°C, while roasting at 200°C for 15 minutes produces coffee beans with optimal roasting levels. These findings provide new insights into optimizing the coffee roasting process to achieve the desired quality of coffee beans.

**Keywords**: coffee, temperature, Arabica, roasting

## INTRODUCTION

The Coffee commodity in Indonesia plays a crucial role in contributing to the country's income, particularly through foreign exchange earnings and support for the local economy. Approximately 95% of coffee plants are managed by smallholder farms, while the remaining are operated by large-scale plantations (Martauli, 2018). Despite Indonesia ranking fourth in coffee exports, its position is still dominated by primary products. As a tropical country, Indonesia is the third-largest global coffee producer after Brazil and Colombia. The majority of coffee varieties grown in Indonesia are Arabica and Robusta. Meanwhile, there is a growing demand for high-quality coffee with flavors preferred by consumers (Spence & Carvalho, 2020). Indonesia is renowned for its coffee, which has a strong body and flavor, making it an ideal choice for blending. The quality of coffee is heavily influenced by handling during harvesting and post-harvest processes (Krishnan, 2017). Coffee harvested when fully ripe tends to have high quality, while

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picking unripe coffee may result in a less optimal aroma and taste. Mixing old and young coffee by traders can lead to a decline in the produced coffee's quality (ANWAR, n.d.). The roasting process is key to shaping the taste and aroma of coffee beans. The uniformity of size, specific gravity, texture, moisture content, and chemical structure of coffee beans facilitates control over the roasting process (Fadri et al., 2019). However, coffee beans exhibit significant differences, making roasting an art that requires skill and experience in line with consumer demands. Roasting is carried out at high temperatures, ranging from 180 to 240°C, usually taking 15 to 20 minutes. During roasting, coffee beans are stirred to ensure rapid water vapor release and even heat distribution. After completion, coffee beans must be promptly removed and rapidly cooled. However, excessive roasting time can lead to over-roasting, emphasizing the critical importance of roasting process control (Bustos-Vanegas et al., 2018).

Several studies have highlighted the influence of roasting time on the coffee flavor profile (Wang et al., 2022) asserted that roasting time directly affects the coffee flavor profile. This research involves sensory analysis to understand how changes in roasting time can influence the taste and aroma of coffee. A study conducted by Schenker et al. (Schenker et al., 2002), focused on the chemical component analysis of coffee beans during roasting. The results of this study indicate that excessive roasting time can trigger chemical reactions that produce compounds contributing to overroast characteristics in coffee. These findings align with studies (Fadri et al., 2019), (Ghani & Hamidah, n.d.) on the influence of temperature and time on the color of coffee beans, which found that changes in roasting time, along with temperature, can affect the color of coffee beans. Overroasting can be reflected in observable color changes in coffee beans that have been roasted for too long.

This research aims to examine the coffee roasting process using conduction heat. In general, this study will analyze the changes in the physical properties of coffee beans during roasting at various temperatures. Information regarding changes in the physical properties of coffee during the roasting process has been limited thus far.

## RESEARCH METHODS

In this study, the dry coffee roasting process was conducted using a roasting machine with a quantity of 500 grams. The material used in this research is Arabica Solok coffee obtained from the Surian Permei Farmer Group (Gapoktan) plantation in Solok Regency, West Sumatra. Roasting was carried out for 12 minutes with temperature variations of 160°C, 180°C, 200°C, and 220°C. The surface plate temperature and material temperature were measured at 2-minute intervals. Temperature measurements were performed using a thermocouple attached to the roasting machine. Temperature adjustments could be made by regulating the gas cylinder's regulator. Subsequently, samples were taken at each time interval. The moisture content in the material was measured using the gravimetric method by oven-drying 5 grams of coffee at various temperatures. To measure hardness, a test was conducted using a universal texture analyzer, while color testing was performed using a colorimeter.

Color parameters were measured using three color components in the Lab color model: L* (luminosity), a* (green-red axis), and b* (blue-yellow axis). L* measures the brightness or darkness level of a color, with values ranging from 0 (black) to 100 (white). Higher L* values indicate brighter colors. a* measures how much a color tends toward green or red. Positive values indicate a more red color, while negative values indicate a more green color. b* measures how much a color tends toward blue or yellow. Positive values indicate a more yellow color, while negative values indicate a more blue color (Zhao et al., 2023), (Windy & Dewi, 2023). Changes in

L*, a*, and b* values were observed to depict the color changes of coffee beans during the roasting process at different temperatures. Figure 1 illustrates the use of the CIELAB color space.

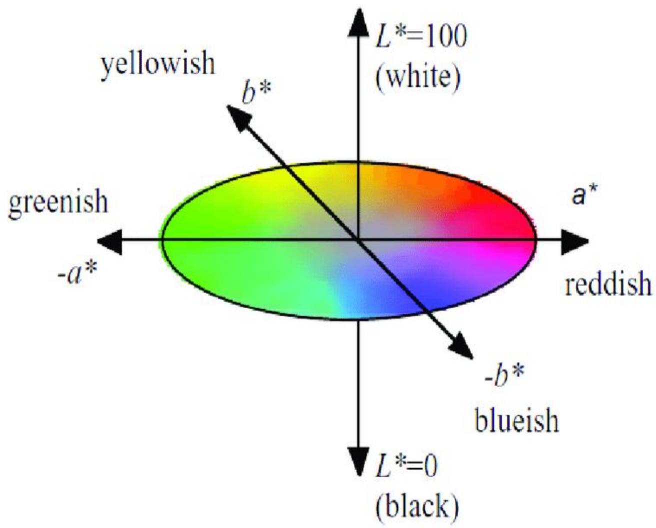


Figure 1. Illustration of CIELAB color space (Molino, J. A et al., 2013).

## RESULTS AND DISCUSSION

1. Temperature Profile During Roasting

Throughout the roasting process, there is a heat transfer from the heating surface into the material. Heat penetrating the material causes temperature changes within, known as sensible heat. This condition peaks when the material temperature approaches the roasting temperature and can be considered to have reached a saturated state. At this stage, changes in mass (water) within the material occur due to the latent heat of evaporation (Fadai et al., 2017). This phenomenon is detailed in Figure 2, a graph depicting temperature changes on the pan and material temperature over the course of roasting at 160°C. From the graph, it can be observed that the increase in material temperature occurs in the time interval between 0 and 8 minutes. However, in the subsequent time intervals, the material temperature remains relatively stable, indicating that significant temperature changes occur at the beginning of the process. From 8 minutes until the end, the material temperature tends to remain constant. This is due to the fact that the material temperature is approaching the pan temperature, causing the heat transfer from the pan to the material to become increasingly smaller.

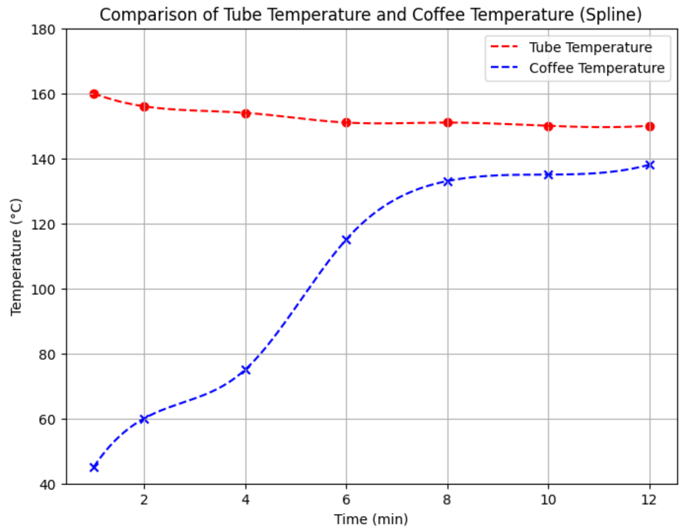


Figure 2. Temperature change curve over time with a roasting level of 160°C.

Materials experiencing more significant water loss will undergo changes in their physical and thermal properties, thereby affecting the temperature increase of the material. This change is related to the water content of the material. The higher the water content, the easier heat will pass through the material, resulting in an increase in material temperature. As the water content decreases, the physical and thermal properties also change, slowing down the temperature increase. This explains why the temperature during roasting at 220°C increases more rapidly compared to temperatures of 200°C, 180°C, and 160°C. Thermal conductivity is a constant whose value depends on the type of material. In most materials, thermal conductivity increases with an increase in temperature, but the variation is very small and can be negligible. If the thermal conductivity value is high, the material easily allows the passage of heat energy. Conversely, if the conductivity is low, the material hinders the passage of heat energy.

Coffee roasting data indicates that at 160°C, there is a tendency for coffee weight to decrease over time. At the 12-minute time interval, a weight loss of 12.59% was recorded, indicating significant roasting. However, at 8 minutes, the weight loss decreased to 7.43%, indicating a slowdown in the roasting process. In the 6-minute interval, further weight loss decreased to 5.87%, indicating a slower roasting phase. Meanwhile, at 200°C, there is an overall increase in the level of weight loss. At the 12-minute time interval, the weight loss reached 14.92%, indicating a higher roasting intensity. At 8 minutes, weight loss slightly decreased to 12.8%, but still reflected a significant roasting. In the 6-minute interval, further weight loss decreased to 7.28%, indicating a potential faster roasting phase during this period. At 220°C, there is a significant increase in the rate of weight loss. At the 12-minute time interval, weight loss peaked at 18.25%, indicating the most intensive roasting compared to other temperatures. At 8 minutes, weight loss reached 15.12%, indicating that roasting intensity remains high during this interval. Although it dropped slightly, weight loss at the 6-minute interval is still quite high, at 13.01%, indicating a consistently strong roasting at this high temperature. These results indicate that temperature affects water content, where at higher temperatures and longer times, there is a significant weight loss, as seen in Figure 3.

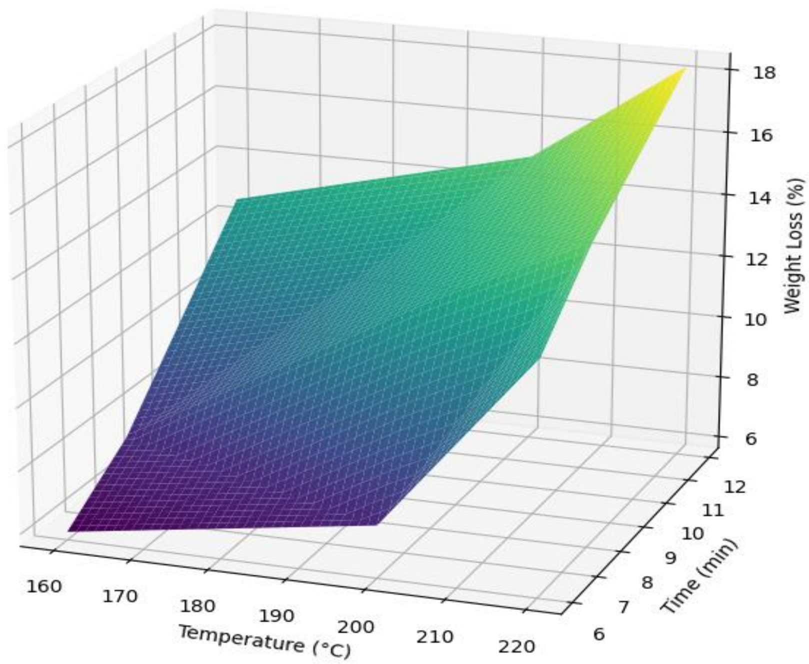


Figure 3. Relationship between temperature, time, and weight loss.

2. Changes in Moisture Content

During the roasting process, there is heat transfer from the pan (roasting medium) to the material, as well as a transfer of water mass. The heat leads to changes in the water mass of the material due to the latent heat of evaporation. Changes in water mass occur when the water content in the material reaches a saturated condition, causing the water within the material to change from a liquid phase to a vapor. This change is clearly evident in the fluctuation of moisture content over time, as illustrated in Figure 4.

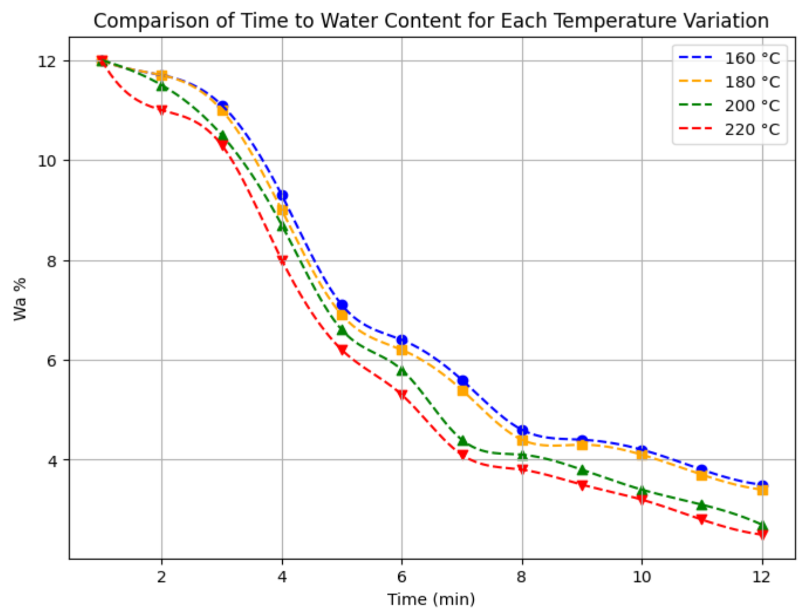


Figure 4. Curve of changes in moisture content (wa) over time during coffee roasting with temperature variations.

In Figure 4, it can be observed that the moisture content of coffee decreases as time progresses. Changes in moisture content during roasting result in corresponding changes in the weight of the roasted coffee. The weight change is proportional to the change in moisture content. Changes in moisture content and coffee weight during the roasting process are measured every 2 minutes. In the roasting period between 0 and 6 minutes, rapid changes in moisture content are evident. Then, from minute 8 to 12, a slower change in moisture content is observed. This result aligns with Clarke's statement (Esquivel & Jiménez, 2012), which suggests that in the early stages of the process, the available heat energy in the roasting chamber is used to evaporate water. The moisture content of coffee beans decreases rapidly at the beginning of roasting and then proceeds relatively slowly towards the end of roasting. This phenomenon is related to the diffusion rate of water (diffusion) within the cell network of coffee beans. As the water content in coffee beans decreases, the evaporation rate decreases because water molecules are located further from the surface of the beans.

The changes in moisture content in the coffee also show that the final moisture content for each roasting temperature is different. The moisture content at the 12-minute mark for roasting at temperatures of 160°C, 180°C, 200°C, and 220°C is 3.72%, 3.65%, 2.13%, and 1.81%, respectively. This indicates that the higher the initial temperature of the drying air, the greater the heat transfer from the roasting medium into the material, resulting in a larger mass transfer through evaporation. It can be understood that during roasting, heat and mass transfer occur simultaneously, similar to the drying process, and can be analogized to the drying equation. The drying rate is generally described by the drying equation based on the analogy of Newton's drying law. The moisture content equilibrium of the material is equal to zero (Me = 0) when the vapor pressure of the material is equal to the vapor pressure of the air (Alves, G. E. et al., 2013) [15]. The amount of water released by the material depends on its temperature. The rate of moisture content reduction is influenced by the coefficient of the moisture content reduction rate (Kx). The calculated values of the observed coefficient of the moisture content reduction rate (Kx) for various temperature variations can be seen in Table 1.

Table 1. Observed Kx values with various roasting temperature variations.

| **Temperature (°C)** | **Kx observation (1/sekon)** |
|---|---|
| 160 | 0,088 |
| 180 | 0,115 |
| 200 | 0,148 |
| 220 | 0,184 |

3. Changes in Hardness

Based on Figure 5, which shows the fracture stress curve (σrupt) during roasting over time with various temperature variations, it can be observed that the change in fracture stress (σrupt) with different roasting temperatures indicates a softening phase. The material undergoes softening at various temperatures during roasting. Materials roasted at higher temperatures have lower average rupture stress values (σrupt), while those roasted at lower temperatures have higher average rupture stress values (σrupt). From the four temperature variations during roasting, it is evident that as the temperature increases, the hardness of the material decreases. This proves that the roasting temperature influences the hardness value of the material. The temperature used in roasting affects the rate of moisture reduction in the material, which, in turn, affects the rate of hardness change in the product. When the temperature is higher, the moisture content of the material decreases more rapidly, causing the coffee to become softer (Cordoba et al., 2020) [16].

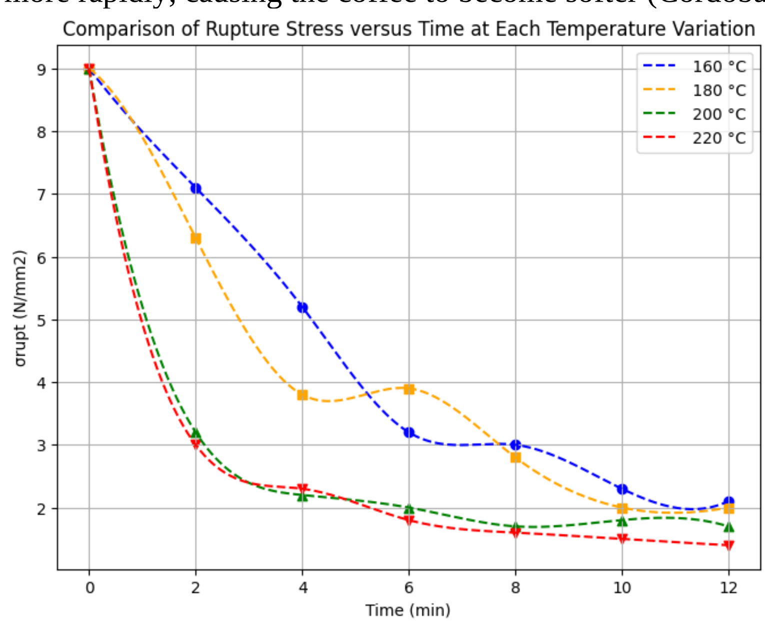


Figure 5. Curve of changes in fracture stress during roasting over time with various temperature variations.

4. Changes in Color Index

Color parameters were measured using three color components in the lab color model, namely L*, a*, and b*. Figure 6 illustrates the changes in each color indicator at various temperatures over the duration of roasting. The observations of the a* parameter in the lab data, representing the color indicator of coffee, show significant effects of temperature and time. At 160°C, the a* parameter indicates a relatively stable color change, starting at 5 at the 2nd minute and reaching 6.9 at the 12th minute. The temperature of 180°C shows a more dynamic variation, with the a* parameter consistently increasing until it peaks at the 10th minute (9.8), then sharply decreasing to 6.2 at the 12th minute. The temperature of 200°C exhibits complex fluctuations, with the a* parameter increasing from 5.4 at the 2nd minute to reaching its peak at the 6th minute (7.2), and then experiencing a sharp decrease to 5.5 at the 10th minute. Meanwhile, at 220°C, the a* parameter shows a rapid increase from 5 at the 2nd minute to peaking at the 6th minute (8.2). However, there is a drastic decrease to 3.3 at the 12th minute. Overall, the analysis of the a* parameter provides insights into the color changes of coffee related to roasting temperature and time. In the observation of b*, there is a tendency for the value to decrease over time and with an increase in roasting temperature. In the early minutes, the b* value is relatively high, indicating the presence of a yellow color in the coffee. However, over time and with an increase in temperature, the b* value tends to decrease. At 160°C, the b* value experiences limited fluctuations, but there is a general tendency for a decrease over time. The temperature of 180°C shows a similar change, with the b* value generally decreasing throughout the roasting time. At temperatures of 200°C and 220°C, the decrease in the b* value is more pronounced, indicating that the yellow color in the coffee undergoes a more significant reduction with an increase in temperature. In general, the observation of b* indicates that the intensity of the yellow color in the coffee tends to decrease during roasting, and this process is accelerated with an increase in temperature and longer roasting time. In the observation of L*, roasting at 160°C and 180°C shows L* values that do not change much. However, roasting at 200°C and 220°C shows a tendency for a decrease in L* values. The a* value also tends to increase, caused by the change in the color of coffee beans to brown and darker hues. This occurs due to the Maillard reaction, resulting in the formation of carbonyl compounds (reducing groups) and amino groups. The Maillard reaction is a non-enzymatic browning reaction that produces complex compounds with high molecular weights (Zhao et al., 2023). The non-uniformity of the color of coffee beans before roasting results in an uneven color during roasting. This leads to unstable lightness levels. However, in general, the obtained data can depict the changes in brightness and color of coffee beans during roasting.

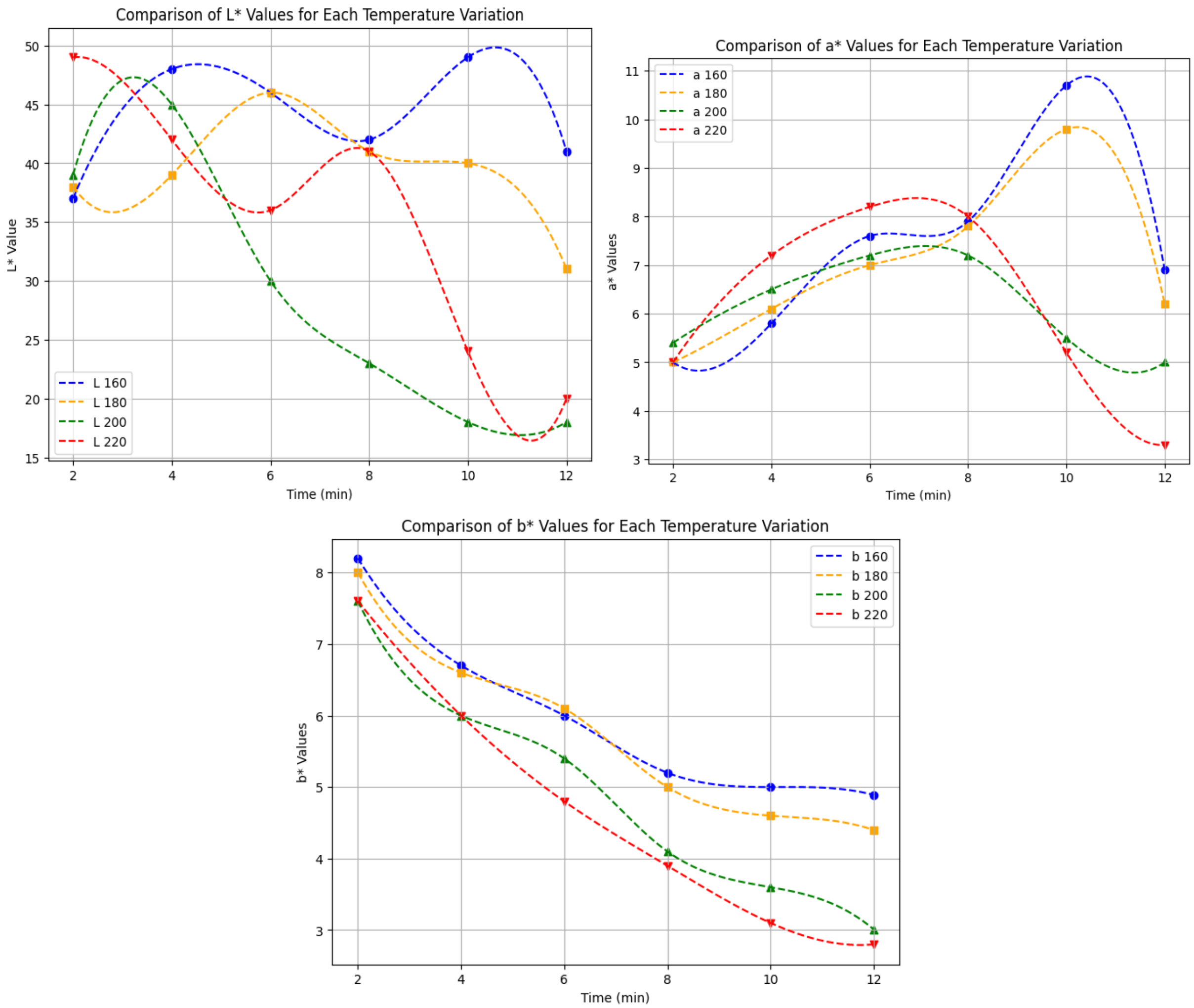


Figure 4. Changes in color index (L, a, b) of coffee during roasting with various temperature variations.

## CONCLUSION

Roasting coffee with temperature variations results in significant changes in the physical properties of coffee beans. This process induces a faster decrease in moisture content, increased brittleness, and an acceleration of color changes towards darkness. Roasting at low temperatures, such as 160°C, produces coffee beans that are not fully roasted after 12 minutes, as indicated by the less dominant color and aroma changes. In contrast, roasting at 200°C for 10 minutes produces well-roasted coffee beans. During the roasting process, the texture of coffee beans tends to be more brittle, as indicated by the significant fracture stress values. This reflects that roasting temperature plays a crucial role in shaping the physical characteristics of coffee beans, directly influencing the degree of roast, aroma, and texture of the final coffee beans.

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