Effect of tooth immersion in the coffee drink with different types of coffee roast temperature on tooth discoloration

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Abstract. We analyzed the effect of coffee bean roasting temperatures on tooth discoloration. A total of 18 post-extracted premolar teeth were immersed in coffee beverage made with beans roasted at 210 °C, 230 °C, or 250 °C for 20 min. Specimens were divided into three groups. The change in color values L*, a*, b*, and E* was measured using the CIE L*a*b* system through the Vita Easy Shade instrument, and the content of polyphenol and tannin of coffee beans was tested. There were significant changes in tooth color because of the different coffee bean roasting temperatures, especially after immersion for 60 h in coffee at which the beans were roasted at 250 °C. In conclusion, changes in tooth color occurred after immersion in coffee beverage despite different coffee roasting temperatures.

1. Introduction
Dentin discoloration has become a problem in dental practice, so various ways to eliminate dentin discoloration have become the object of research for many years. Color changes in teeth can be caused by extrinsic stains through deposition of chromogenic materials on tooth surfaces, such as tobacco, tea, and coffee, as well as extrinsic spots through the buildup of chromogenic substances in the dental structure of dentin [1].

Coffee is a popular drink consumed daily by the community. People generally consume a cup of coffee a day for 5–10 min. It is worth noting that coffee drinks are a chromogenic agent containing dyestuffs (tannins) that are known as color change agents in teeth [2,3]. Tannins act as dye and color binders and can cause a brown color [4]. However, the content of tannins in coffee beans can be reduced through the process of wet seed processing [5]. Other content consists of chlorogenic acid, which is a major phenolic compound in coffee and has a role in the formation of color, flavor, and aroma of coffee beverages [2]. Increased content of chlorogenic acid may lead to decreased coffee drink pH values below 5.5 [6]. The pH of an acidic beverage can lead to demineralization, which dissolves calcium hydroxyapatite in the enamel of teeth. Therefore, it creates more pores on the surface of the enamel, which facilitates deposition of dyestuffs, such as tannin, into the dental enamel, especially when exposed to deep-water coffee for a long time [7,8]. Chlorogenic acid content can be reduced through the temperature setting at the time of coffee bean roasting. High temperatures during drying cause chlorogenic acid reduction by more than 60%, resulting in increased coffee pH because of the chlorogenic acid destruction at the time of drying [9,10]. Roasting is a process that depends on
time and temperature. During roasting, there is a change in the chemical composition of the coffee beans, which produces hundreds of chemical compounds that have a role in the formation of flavor, aroma, and color in coffee drinks. Generally, coffee beans are roasted at 180 °C–240 °C for up to 20 min [11]. Mwithiga et al. [6] obtained pH below 5.5 when coffee was roasted at 170 °C, 190°C, and 210 °C for 20 min. The pH of an acidic coffee beverage may lead to demineralization and facilitate deposition of tannins into the dental enamel. However, according to Duarte et al., [2] the pH of coffee drinks will increase as the temperature of the coffee beans is increased.

It is not yet known whether Arabica coffee beans, originating from Indonesia with higher roasting temperatures (which results in pH above the 5.5 critical pH for demineralization of tooth enamel), will not lead to demineralization that facilitates entry of tannin substances into the enamel and how roasting coffee beans at temperatures of 210 °C, 230 °C, or 250 °C within 20 min will affect tooth color change.

2. Methods
This laboratory experiment was approved by the Dental Research Ethics Committee, Faculty of Dentistry, Universitas Indonesia. The 18 post-extraction human premolar teeth specimens used were divided into three groups based on roasting temperatures of 210 °C, 230 °C, or 250 °C. Each group was given four treatment times (beginning/without immersion in coffee drinks and after immersion for 30, 45, or 60 h) so that six specimens were required in each treatment group. The entire root surface of the tooth was smeared with colored nail polish so that no coffee could penetrate into dentin tubules.

This study used Arabic Gayo coffee beans, which have been wetly processed and roasted at 210 °C, 230 °C, or 250 °C for 20 min using closed smoke exiting methods. Prepared specimens were divided into three groups to be immersed for 30, 45, or 60 h in a coffee drink made from these beans. The specimens were immersed in coffee drinks at a temperature of 37 °C and then stored in a 37 °C incubator. A new drink was made for each immersion.

Before and after immersion in coffee drinks, dental specimen measurements were obtained using Vita Easy Shade and recorded as L* (brightness), a* (red–green range), and b* (yellow–blue color range). The color change of the tooth enamel was measured after a 30-h immersion, and then, immersion was continued for another 15 h for a total immersion of 45 h. The color change of the 45-h immersion specimen was measured, and immersion was continued again for another 15 h to achieve a total immersion of 60 h. The final color change was measured after 60 h of immersion.

The immersion groupings were analyzed using repeated analysis of variance (ANOVA) and Wilcoxon (post hoc from Friedman) tests, and the coffee data were analyzed using the one-way ANOVA method, followed by the post hoc least significant difference (LSD) and Mann–Whitney U tests (post hoc from Kruskal–Wallis test).

3. Results
The calculation results were obtained by the formula: E* ab = [(L*) 2 + (a*) 2 + (b*) 2] 1/2. To compare the color changes between coffee bean roasting temperatures during each immersion time, the one-way ANOVA test was performed. In Table 1, after 30 h, the mean tooth color change in the 250 °C group was significantly higher than that in the 210 °C and 230 °C groups. Likewise, after 45 h of immersion, the tooth color change in the 230 °C group was significantly higher than that in the 250 °C group, but it was not significant compared to that in the 210 °C group. After 60 h, the color change was higher in the 250 °C group compared to that in the 210 °C group, but it was not significant compared to that in the 230 °C group. This finding suggested that dental color change becomes much darker with beans roasted at 250 °C.
To the compare the color changes between immersion times in each roasting temperature group, repeated ANOVA was performed. In Table 1, the 210 °C roasting temperature appears to cause a significant reduction in tooth decay values after immersion for 30–60 h. The color change was more toward brightness. However, at 230 °C, there was a significant increase in tooth color change between 30 and 60 h of immersion. The color change again was more toward brightness. In contrast to the 210 °C and 230 °C groups, the 250 °C group had decreased tooth color change values after 45 h so that the tooth color changed more toward the light, but then after 60 h of immersion, the values increased significantly, and the color change was more toward the dark.

To compare the color changes between roasting temperatures at every time of immersion, the Mann–Whitney U test was performed. In Table 2, during a 30-h immersion, the highest brightness (L*) change occurred in the 230 °C roasting temperature group, and the change was not significant when compared to that in the 230 °C and 250 °C groups. The results after 60 h of immersion showed the highest L* decrease in the 250 °C group compared to the 210 °C and 230 °C groups (not significant).

| Roasting time | Immersion 30 h | Immersion 45 h | Immersion 60 h |
|---------------|---------------|---------------|---------------|
| Coffee Bean   | ΔE*           | ΔE*           | ΔE*           |
| 210 °C        | 10.24         | 9.61          | 8.21          |
| 230 °C        | 10.69         | 11.20         | 11.81         |
| 250 °C        | 14.74         | 7.42          | 13.46         |

Table 1. Average value (ΔE *) on tooth specimens after treatment

To compare the color changes between soaking times in each roasting temperature group, the Wilcoxon test was performed. In Table 2, the 210 °C and 230 °C groups had a decrease in L* after immersion for 30 h; then, after 45 and 60 h, the L* level increased. The highest degree of L* change was observed in specimens immersed for 45 h, although it was not significant compared to that after 30 h of immersion. However, after immersion for 60 h, the degree of L* change decreased significantly compared to that after 45 h of immersion. In the 250 °C group, the degree of L* decreased after 30 h of immersion and then increased after 45 h and decreased again after 60 h of immersion. The highest degree of L* change was observed in specimens immersed for 45 h, although it was not significant compared to that after 30 h of immersion. The 60-h immersion decreased the change in L* degree, which was not significant compared to that after 45 h of immersion.

To compare the color changes between roasting temperature groups at every time of immersion, the Mann–Whitney U test was performed. In Table 3, during a 30-h immersion, the highest reddish (a*) change rate occurred in the 250 °C roasting temperature group. The change was a reddening degree and was significantly different compared to that in the 230 °C and 210 °C groups. After immersion for 45 h, the highest a* degree change occurred in the 230 °C group, but this change was not significant when compared to that in the 210 °C and 250 °C groups. After 60 h of immersion, the highest a* degree change occurred in the 250 °C group, with a significant increase in the a* degree compared to
that in the 210 °C group. However, this difference was not significant compared to that in the 230 °C group.

Table 3. Average of $a^*$ and $\Delta a^*$ in tooth specimens before and after treatment

| Roasting Temperature | Before Immersion | Immersed 30 h | Immersed 45 h | Immersed 60 h |
|----------------------|------------------|---------------|---------------|---------------|
| Coffee Bean          | $a^*$ | $\Delta a^*$ | $a^*$ | $\Delta a^*$ | $a^*$ | $\Delta a^*$ |
| 210 °C               | 0.96 | 4.63 | 3.67 | 2.92 | 1.96 | 2.97 | 2.01 |
| 230 °C               | 1.53 | 5.1 | 3.56 | 4.49 | 3.19 | 5.22 | 3.68 |
| 250 °C               | 0.99 | 7.78 | 6.78 | 3.39 | 2.39 | 7.11 | 6.11 |

To compare the color changes between immersion times in each roasting temperature group, the Wilcoxon test was performed. In Table 3, teeth in the 210 °C and 230 °C groups experienced an increase in $a^*$ after immersion for 30, 45, or 60 h. After 45 h of immersion, there was a decrease in $a^*$ when compared to that after 30 h of immersion. However, after immersion for 60 h, there was a significant change in $a^*$ compared to that after 45 h of immersion.

In the 250 °C roasting temperature group, the degree of $a^*$ increased after immersion for 30, 45, or 60 h. After 45 h of immersion, there was a significant decline in $a^*$ compared to that after 30 h, and after 60 h of immersion, there was a significant change in $a^*$ compared to that after 45 h.

To compare the color changes between roasting temperatures during each immersion time, the one-way ANOVA test was performed. In Table 4, during a 30-hour immersion, the highest degree of yellowish ($b^*$) change occurred in the 250 °C group. The change was a yellowish degree increase and was significant when compared to that in the 230 °C and 210 °C groups. After immersion for 45 h, a higher degree of $b^*$ change occurred in the 230 °C group, with a significant increase in $b^*$ compared to the 250 °C group. However, the difference was not significant when compared to the 210 °C group. After 60 h of immersion, the highest degree of $b^*$ occurred in the 250 °C group. The change was a yellowish degree increase and was not significant when compared to the 230°C and 210 °C groups.

Table 4. Average values of $b^*$ and $\Delta b^*$ before and after tooth specimen treatment

| Roasting Temperature | Before Immersion | Immersed 30 h | Immersed 45 h | Immersed 60 h |
|----------------------|------------------|---------------|---------------|---------------|
| Coffee Beans         | $b^*$ | $\Delta b^*$ | $b^*$ | $\Delta b^*$ | $b^*$ | $\Delta b^*$ |
| 210 °C               | 26.06 | 34.42 | 8.36 | 33.35 | 7.28 | 33.31 | 7.24 |
| 230 °C               | 26.12 | 34.79 | 8.67 | 34.95 | 8.83 | 36.51 | 10.39 |
| 250 °C               | 27.99 | 40.51 | 12.51 | 33.49 | 5.49 | 38.66 | 10.66 |

To compare the color changes between immersion times in each roasting temperature group, a repeated ANOVA was performed. In Table 4, teeth in the 210 °C group showed an increase in the degree of $b^*$ after immersion for 30, 45, or 60 h. There was a decline in the degree of yellowish change ($\Delta b^*$) after 45 h (not significant when compared to 30 h) and 60 h (not significant when compared to 45 h) of immersion. However, in the 230 °C group, the degree of $b^*$ also increased after immersion for 30, 45, or 60 h. The degree of $b^*$ increase was not significant when comparing between 30 and 45 h and between 45 and 60 h of immersion. In the 250 °C group, the degree of $b^*$ again increased during immersions of 30, 45, or 60 h. The degree of $b^*$ decreased significantly after 45 h of immersion compared to that after 30 h and increased significantly after 60 h compared to that after 45 h.
4. Discussion

Mwihiga et al. [6] used 210 °C as the coffee bean roasting temperature. In our research, coffee beans were roasted at 230 °C, 250 °C, and 210 °C temperatures for 20 min using a closed exhaust method. Chlorogenic acid was analyzed using the polyphenol content test because the acid concentration of chlorogenate is proportional to the overall polyphenol concentration [12]. By the polyphenol content test, the lowest polyphenol content at the 250 °C temperature was 3.48%. Therefore, the 250 °C roasting temperature caused a decrease in chlorogenic acid content. This is in line with the findings of Adriana et al. That the content of chlorogenic acid decreases along with increasing roasting temperature. Since the polyphenol content was higher at roasting temperatures of 210 °C and 230 °C than at 250 °C, both temperatures were presumed not to result in perfect chlorogenic acid degradation [5].

In the coffee pH test, the highest pH values of coffee were 4.84, 4.80, and 4.68 in the 230 °C, 250 °C, and 210 °C groups, respectively. This finding was different from that of Duarte et al. [2] who reported that coffee drink pH increases as the temperature increases. The reduction in the pH of coffee in the 250 °C group may be due to lower chlorogenic acid levels at higher roasting temperatures, thus increasing the concentration of other acids at the time of drying. This is in line with the findings of the previous study that the higher the roasting temperature, the lower the chlorogenic acid content, whereas the concentrations of quinic, gallic, and sinapic acids increased [13]. The pH of coffee drinks in the three roasting temperature groups showed values below the critical point of enamel (5.5), which allows demineralization during immersion for 30, 45, or 60 h. Similarly, Prasetyo reported that the acidity of drinks with pH less than 7 (acidic) might cause demineralization of the surface of the enamel after immersion for 12 h [14].

In the 210 °C and 230 °C groups, the dehydration value of the teeth (ΔE) decreased with the duration of roasting, but this was not significant, although in the 230 °C group, the dehydration increased tooth changes as the duration of immersion increased. As a result, coffee drinks with coffee beans roasted at 210 °C do not affect tooth discoloration. The polyphenol content test results showed that, at a temperature of 210 °C, chlorogenic acid degradation is slightly less than the polyphenol content before discharge. This may not have been due to the pyrolysis reaction and the Milliard reaction, which result in the production of melanin-producing melanoids because of chlorogenic acid degradation. According to Buffo et al. [15], the pyrolysis reaction starts at temperatures of 210 °C through the release of heat energy or an exothermic reaction. At the 250 °C level, the polyphenol rate is less than that before the assay, with the assumption that chlorogenic acid is degraded in larger quantities. This allowed the pyrolysis and Milliard reactions, which resulted in the production of brown melanin-producing melanoids because of the degradation of chlorogenic acid in large numbers, resulting in dental discoloration. The decline in tooth color changes after 45 h was less than that after 30 and 60 h of immersion. It is suspected that some chromogenic agents in dental enamel were dissolved because of soaking in coffee drinks with low pH, resulting in a decrease in color change during the 45-hour immersion. However, during the 60-hour immersion, there was an increase in the color change that allegedly was caused by deposition of chromogenic agents on tooth enamel.

During the 30- and 60-hour immersions, the change in tooth values (ΔE) was significantly lower in the 210 °C group compared to the 250 °C group, but not significantly different compared to that in the 230 °C group. Likewise, during the 45-hour immersion, tooth discoloration values were lower in the 210 °C group, but the change was not significant compared to that in the 230 °C and 250 °C groups. This may be due to the yielding coffee beans at a temperature of 210 °C, which has not yet caused the pyrolysis reaction producing acids other than chlorogenic acid, namely, gallic acid, sinapic acid, and quinine acid, which induce formation of red dyes, along with the content of condensed tannins, thus causing a lower color change at 210 °C roasting temperature. During immersion for 45 h, it is suspected that some of the chromogenic agent’s dissolved tooth enamels because of immersion in coffee drinks with low pH value, resulting in meaningless color changes.

During immersion for 30 h, the value of tooth color change (ΔE) in the 230 °C group was significantly lower than that in the 250 °C group, but this change was not significant after 60 h of
immersion. This may be due to the coffee drink yielding coffee beans at 230 °C boiling temperature, but the pyrolysis reaction not yet producing gallic acid, sinapic acid, and quinine acid, which induce the formation of dyes along with condensed tannin content, resulting in lower color changes. Then, during the 45-hour immersion, the 230 °C dry-temperature group experienced greater and significant tooth change values (ΔE) than the 250 °C group. This may be due to the deposition of dyestuffs, such as tannins and melanoids, that are in larger concentrations after 45 h of immersion and that are chromogenic agents on tooth enamel because of the low pH of the coffee drink. The low pH of the drink causes damage to calcium hydroxyapatite in the tooth, thus causing the tooth enamel to dissolve, which, in turn, causes the formation of small pores on the enamel surface and facilitates the deposition of chromogenic agents, such as tannin and melanoid substances, that are more abundant in dental enamel. This is in line with the findings of Ghavamnasiri et al. That the lower pH of coffee and tea would be affected by environment compared to chlorogenic acid [8]. However, during the 30- to 60-hour soaking time, the dental change in the 230 °C roasting temperature group was greater than (but not significant) that in the 210 °C group. This may be due to the degradation of chlorogenic acid at the approximate temperature ranges of 210 °C and 230 °C when viewed from the almost proportionate amount of polyphenol, so it did not affect the dental discoloration.

At temperatures of 210 °C, 230 °C, and 250 °C, there was a decrease in the mean L* value during the ineffective 30-hour immersion. This decrease in L* was due to the 2.56% tannin content, which can cause tooth change to the darker color. This is in accordance with Norbho's [16] research that tannins can cause tooth discoloration in vivo and in vitro. Then, soaking for 45 and 60 h increased the degree of L*. The degree of L* changes that occurred may be due to the low pH of the coffee drink causing dissolution of the chromogenic agent on the surface of the tooth enamel, so the deposited chromogenic agent is detached from the surface of the enamel and increases the degree of L*. However, the 250 °C group experienced a decrease in the degree of L* during the 60-hour soaking chromogenic agent was suspected to be deposited back (the tannin substance in the enamel) so the teeth became darker.

During the 30- and 60-hour immersions, there was a lower and significant a* change in the 210 °C group compared to the 250 °C group, but it was not significant during 45 h of immersion. During immersion times of 30–60 h, the 210 °C group had a lower degree of reddening, which was not significant when compared to the 230 °C group. Coffee is a source of food that contains condensed tannins, which, if contacted with enzymes or acids, can provide a red pigment [17,18]. The low-temperature roasting process allows the chlorogenic acid levels to be present in larger quantities than at high temperatures. High temperatures lead to reduced chlorogenic acid but lead to the formation of other acids, such as quinine, gallic, and sinapic acids [12]. The reactions between acids formed with condensed tannins allow the formation of larger red pigments at high roasting temperatures. This may cause a lower reddish color change at a temperature of 210 °C compared to 250 °C. Also, the pH value of the coffee drink that is below the critical point of enamel makes it easy to deposit red dyes into the tooth enamel.

During the 30-hour immersion, there was a significant change in a* degree in the 230 °C group compared to the 250 °C group, whereas during 60 and 45 h of immersion, this change was not significant. Low-temperature roasting processes allow the presence of larger chlorogenic acid levels than those at high temperatures. Higher temperatures lead to reduced chlorogenic acid, but the quantities of quinine, gallic acid, and sinapic acid increase [12]. This condition allows the formation of larger red pigments at higher temperatures. Therefore, there was a reddish color change in the 230 °C group compared to that in the 250 °C group. However, during the 30-hour soaking, the 230 °C group showed a decrease in the degree of reddish color, but this was not significant compared to the 210 °C group, and during 45 and 60 h of immersion, the degree of reddish color change was not significant. This may be due to the degradation of chlorogenic acid between the 210 °C and 230 °C roasting temperature groups based on the proportionate amounts of polyphenols, which were almost comparable, so the a* degree changes were meaningless.
The degree of yellowishness (b*) in the 210 °C, 230 °C, and 250 °C groups increased during immersion for up to 60 h. This is because coffee contains tannins that are white-yellowish to light brown [17]. Also, the coffee pH was below the critical point of demineralized enamel so that it also facilitated entry of tannin substances into the tooth enamel through the formed porosity and led to elevated b* levels in the three roasting temperature groups.

During the 30-hour immersion, the lower and significant change in b* value occurred in the 210 °C group compared to the 250 °C roasting temperature group, but during 60 and 45 h of immersion, this change was not significant. It can be seen from the test results of polyphenol content that at a temperature of 210 °C the amount of chlorogenic acid degradation was not much different than the polyphenol content before being hidden. This may still be in the early stages of drying endothermic reactions through the loss of water vapor and coffee beans turning from green to yellow, but the pyrolysis reaction has not caused changes in chemical composition and compound formation, resulting in a lower color change in the 210 °C group [15]. During soaking times of 30–60 h, the 210 °C group showed a lower degree of b* change, but this was not significant when compared to the 230 °C group. This is because that the amount of polyphenol is almost proportionate between the two roasting temperature groups, which indicates the chlorogenic acid also degraded in almost the same amount so that the degree of yellowish change was not significant.

During the 30-hour immersion, the 230 °C group showed a lower and significant b* degree change compared to the 250 °C group, but it was not significant after 60 h of immersion. Then, during the 45-hour immersion, the 230 °C group showed a change in b*, which may be due to the 230 °C group having yet to undergo the pyrolysis reaction to produce yellowish gallic acid, so that the 230 °C temperature caused a lower degree of b* change [13]. The greater degree of b* change noted during 45 h of immersion was due to the absorption of yellow dyes into tooth enamel because of immersion in coffee drinks with low pH. During immersion times of 30–60 h, there was a larger but slight degree of b* change in the 230 °C group compared to the 210 °C group. This is because that the amount of polyphenol was almost comparable between the 210 °C and 230 °C roasting temperature groups so that chlorogenic acid was degraded in approximately similar quantities, causing an insignificant yellowish degree change.

5. Conclusion
There is a change in color of teeth that are soaked in coffee drinks with different roasting temperatures of coffee beans. The color change of the teeth immersed in coffee drinks with a range of mean values of ∆E * 7.43 to 14.74, which is above the value of ∆E * 3.3, indicates that the change in color is not acceptable clinically.

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