

The Potential of Robusta Coffee Bean Extract (*Coffea canephora*) in Reducing Surface Roughness of Stainless-Steel and CuNiTi Orthodontic Wires

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ARTICLE INFO

Keywords: Robusta Coffee Bean Extract, Stainless-Steel Orthodontic Wire, Cuniti Orthodontic Wire, Surface Roughness, Corrosion Inhibitor

Received : 15 July

Revised : 20 August

Accepted: 30 September

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ABSTRACT

The increased surface roughness of stainless-steel and CuNiTi orthodontic wires caused by corrosion may increase friction and affect wire performance. This study evaluated Robusta coffee bean extract (*Coffea canephora*) at 1.5, 2.0, and 2.5 g/L as a natural inhibitor of surface roughness. A laboratory posttest-control-group experiment used 16 stainless-steel and 16 CuNiTi wires, divided into a control and three treatment groups, immersed for 7 days in artificial saliva with twice-daily extract exposure. Surface roughness (Ra) was measured using a Surface Roughness Tester. One-way ANOVA followed by LSD was used. The 2.0 g/L group showed the lowest mean roughness in both wire types and differed significantly from selected groups. Robusta coffee extract showed potential as a natural corrosion inhibitor

INTRODUCTION

Malocclusion is an abnormal misalignment of the relationship between the upper and lower jaw, with a high prevalence of around 80% in Indonesia (Kemenkes, 2018). One method of correcting malocclusion is orthodontic treatment using orthodontic devices, namely removable or fixed orthodontics. Fixed orthodontic devices have main components in the form of brackets, archwires, and other supporting accessories (Rahardjo, 2012). Archwires function to transfer force to the teeth through brackets, allowing teeth to move to the desired position (Rosen, 2016). The two archwires most often used in fixed orthodontic treatment are stainless-steel and CuNiTi. Stainless-steel orthodontic wires have components consisting of 71% ferrum, 18% chromium, 8% nickel, and 0.2% carbon with high stiffness properties and are more economical than other types of wires (Peniasi et al., 2018). Meanwhile, the components of CuNiTi orthodontic wire consist of 42.99% titanium, 49.87% nickel, 5.64% copper, and 0.5% chromium (Singh, 2008). CuNiTi wire is a development of NiTi wire with the addition of copper (Cu), which improves the mechanical properties of the wire, such as the ability to produce more constant force, higher elasticity, and resistance to permanent deformation (Mahalaxmi, 2018).

Research shows that stainless-steel and CuNiTi orthodontic wires can experience changes in wire characteristics, such as the presence of the time of a rough wire surface, due to the corrosion process triggered by the oral cavity environment, especially in acidic pH conditions. A rough surface can cause some patients soft tissue irritation or allergic reactions (Saputri et al., 2015). In addition, it can increase the friction force between the wire and the bracket, thus inhibiting tooth movement and prolonging the duration of orthodontic treatment (Rosdayanti et al., 2018; Leite et al., 2016). Therefore, this event can be controlled by adding an inhibitor. Inhibitors can come from inorganic compounds or organic materials that can be anti-corrosion agents. One of the organic materials that can be used is Robusta coffee beans (Mulyaningsih et al., 2019).

Robusta coffee beans (*Coffea canephora*) are one type of coffee widely cultivated in Indonesia and are one of the leading commodities (Budi et al., 2020). One of the best Robusta coffee producers in East Java is Jember Regency (Nuraisyah et al., 2024). The use of Robusta coffee beans can not only be enjoyed as a drink but also has the potential to be developed into innovative products, such as corrosion inhibitors and active ingredients in mouthwash, because of their beneficial bioactive compound content. Robusta coffee beans contain active compounds such as alkaloids, flavonoids, chlorogenic acids, tannins, and saponins (Chairgulprasert, 2016; Wigati et al., 2018).

These compounds are known to have the ability to interact with metal ions through functional groups such as -OH and -NH₂, forming a protective layer that reduces the corrosion rate so that surface roughness can also decrease (Pulikkottil et al., 2016; Wei et al., 2020). Previous studies have shown that natural ingredients such as starfruit leaf extract, avocado seeds, and pandan leaves, which contain tannins, flavonoids, and alkaloids, are effective in reducing corrosion on stainless-steel and NiTi orthodontic wires (Herawani et al., 2018; Banjang et al., 2018; Ilyasa et al., 2023).

Based on the description presented, the researcher is interested in observing the benefits of Robusta coffee bean extract in reducing the surface roughness of orthodontic wires made of stainless-steel and CuNiTi.

LITERATURE REVIEW

Research shows that stainless-steel and CuNiTi orthodontic wires can experience changes in wire characteristics, such as the presence of the time of a rough wire surface, due to the corrosion process triggered by the oral cavity environment, especially in acidic pH conditions. A rough surface can cause some patients soft tissue irritation or allergic reactions (Saputri et al., 2015). In addition, it can increase the friction force between the wire and the bracket, thus inhibiting tooth movement and prolonging the duration of orthodontic treatment (Rosdayanti et al., 2018; Leite et al., 2016). Therefore, this event can be controlled by adding an inhibitor. Inhibitors can come from inorganic compounds or organic materials that can be anti-corrosion agents. One of the organic materials that can be used is Robusta coffee beans (Mulyaningsih et al., 2019).

METHODOLOGY

Materials

This study used Robusta coffee beans obtained from the Saeko Kapti Agawe Raharjo (SEKAR) Cooperative, Coffee and Cocoa Research Center, Jember-East Java. The specifications of the Robusta coffee used are green bean coffee that has been finely ground and has gone through a roasting process at a temperature of 175°C for 15 minutes. The type of wire used in this study was American Orthodontics brand stainless-steel and CuNiTi wires.

Methods

This study used a laboratory experimental design with a posttest control group design model. The samples used consisted of 16 stainless-steel and 16 CuNiTi orthodontic wires of the American Orthodontics brand with a rectangular cross-section measuring 0.017 x 0.025 inches and a length of 2 cm, where the wire pieces were taken from the straight section to ensure measurement consistency. The samples were divided into four groups for each group of stainless-steel and CuNiTi orthodontic wires: one control group (C) and three treatment groups (T1, T2, and T3). The control group was soaked in artificial saliva, while the treatment group was soaked in a robusta coffee bean extract solution with concentrations of 1.5 g/L, 2 g/L, and 2.5 g/L, respectively.

This study used robusta coffee bean powder of the Kopi Lanang Robusta brand obtained from the Saeko Kapti Agawe Raharjo (SEKAR) Cooperative, the Jember Coffee and Cocoa Research Center-East Java. The maceration method obtained Robusta coffee bean extract with 96% ethanol solvent. Two hundred fifty grams of coffee bean powder was soaked in 1000 mL of ethanol for two days and then filtered to separate the filtrate and dregs. The filtrate obtained was evaporated using a rotary evaporator to produce a concentrated extract, which was then neutralized with a NaOH base solution to reach pH 6.8.

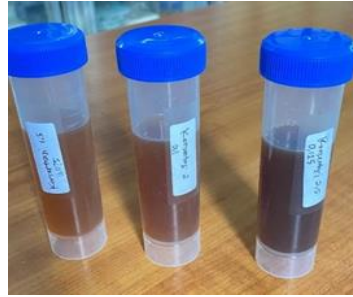


Figure 1. Robusta coffee bean extract dissolved in artificial saliva

The artificial saliva used in this study was made based on the Afnor method, consisting of Na_2HPO_4 0.26 g/L, KSCN 0.33 g/L, NaCl 6.0 g/L, KH_2PO_4 0.20 g/L, KCl 1.20 g/L, and NaHCO_3 1.50 g/L, with the pH adjusted to 6.8 using HCl. Before treatment, all orthodontic wires were cleaned with sterile distilled water, dried in a desiccator for 24 hours, then grouped according to treatment.

Based on the research results of Angeline et al., 2021, the peak corrosion on orthodontic wires in the oral cavity is on the 7th day. In this study, every day, the wire was soaked for 1 minute in robusta coffee bean extract and dissolved in artificial saliva, with a frequency of 2 times a day until the 7th day. After soaking, the wire was cleaned using a solution of H_2SO_4 diluted with distilled water according to the ASTM G1-90 standard to remove corrosion residues, then dried again in a desiccator for 24 hours.

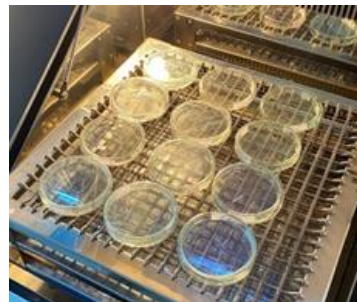


Figure 2. Sample storage process in the incubator

The wire's surface roughness was measured using a Surface Roughness Tester, Kosaka brand, type SE800, with roughness values expressed in Roughness Average (Ra) units.



Figure 3. Surface roughness tester type SE800

Data Analysis

The data were analyzed for normality using the Shapiro-Wilk test and for homogeneity using Levene's test. Significant differences between groups were assessed through one-way ANOVA, followed by the post hoc LSD test.

RESEARCH RESULT

The figures and tables below display research data on the effects of Robusta coffee bean extract (*Coffea canephora*) on stainless steel and CuNiTi orthodontic wires.

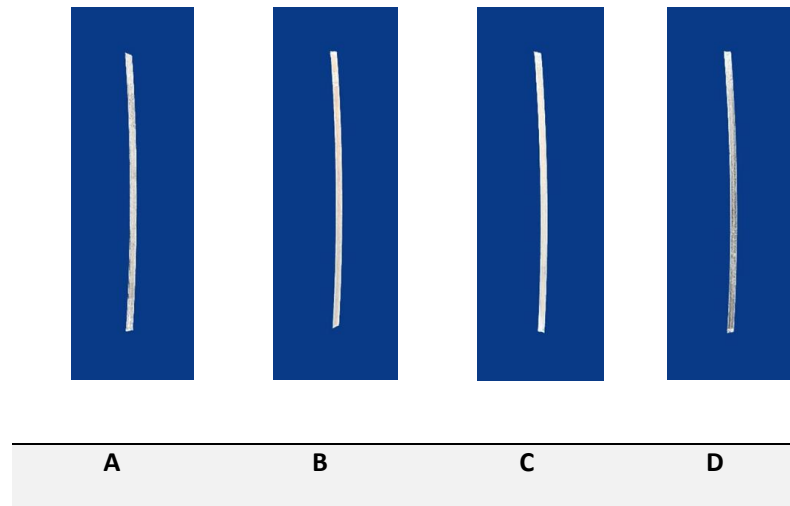


Figure 4. Visual results of surface roughness of stainless-steel orthodontic wire

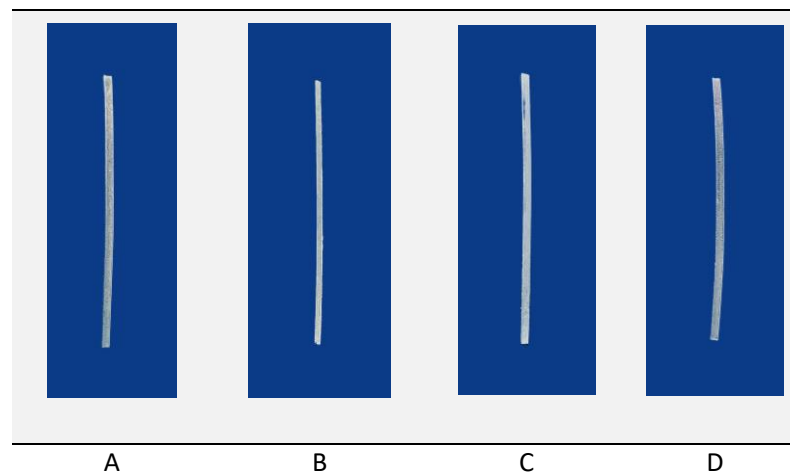


Figure 5. Visual results of surface roughness of CuNiTi orthodontic wire

Information:

- A: Control looks quite rough with some line scratches
- B: Treatment 1 looks quite rough with some line scratches
- C: Treatment 2 looks still smooth with few line scratches
- D: Treatment 3 looks rough with many line scratches

Table 1. Average value of surface roughness of stainless-steel orthodontic wire

Sample Group	Control	T-1	T-2	T-3
1	0,07	0,03	0,03	0,1
2	0,09	0,05	0,03	0,06
3	0,07	0,02	0,02	0,08
4	0,04	0,08	0,01	0,09
Average	0,06	0,04	0,02	0,08

Table 2. Average value of surface roughness of CuNiTi orthodontic wire

Sample Group	Control	T-1	T-2	T-3
1	0,13	0,13	0,07	0,20
2	0,15	0,10	0,09	0,18
3	0,12	0,13	0,07	0,16
4	0,18	0,15	0,14	0,16
Average	0,15	0,13	0,09	0,18

Information:

Control : Control Group (soaked in artificial saliva)

T-1: Treatment 1 (soaked with robusta coffee extract at a concentration of 1.5 g/L)

T-2: Treatment 2 (soaked with robusta coffee extract at a concentration of 2 g/L)

T-3: Treatment 3 (soaked with robusta coffee extract at a concentration of 2.5 g/L)

The visual results of changes in the surface roughness of orthodontic wires in each treatment group can be seen in Figure 4 and Figure 5. This is supported by data in Table 1 and Table 2, which contain the values of the surface roughness test results of stainless-steel orthodontic wires and CuNiTi orthodontic wires in each treatment group. The results of the surface roughness test showed a decrease in the average surface roughness value after administration of Robusta coffee bean extract. The study's results are also presented with bar charts in Figure 6 and Figure 7, which show that the highest surface roughness value was in T-3, while the lowest surface roughness value was in T-1.

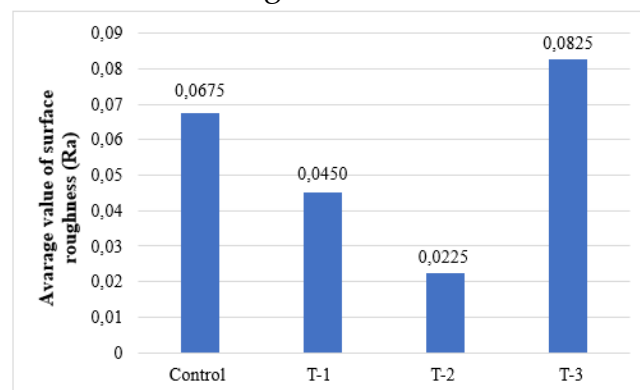


Figure 6. Bar diagram of average surface roughness values on stainless-steel orthodontic wires

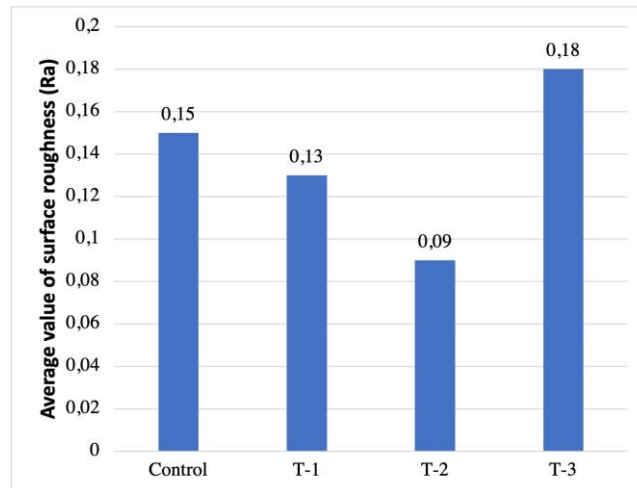


Figure 7. Bar diagram of average surface roughness values on CuNiTi orthodontic wires

The research data were analyzed using the one-way ANOVA and post-hoc LSD tests to determine significant differences between treatment groups. Before the ANOVA test was conducted, the data were analyzed using a preliminary test in the form of a normality test (Shapiro-Wilk) and a homogeneity test (Levene Test). The results showed that the data were normally distributed and homogeneous with a $p\text{-value} > 0.05$. After the data was declared normal and homogeneous, one-way ANOVA test was conducted to determine significant differences between groups.

Table 3. Post-hoc and LSD test results of surface roughness of stainless-steel orthodontic wire

Group	Control	T-1	T-2	T-3
K		0,127	0,007*	0,296
P-1			0,127	0,018*
P-2				0,001*

Table 4. Post-hoc and LSD test results of surface roughness of CuNiTi orthodontic wire

Group	Control	T-1	T-2	T-3
K		0,349	0,013*	0,121
P-1			0,075	0,021*
P-2				0,001*

The test results showed significant differences with a $p\text{-value} < 0.05$, so it was continued with the post-hoc LSD test to determine the average differences between groups. The results showed significant differences between the control and T-2 groups, the T-1 and T-3 groups, and the T-2 and T-3 groups.

DISCUSSION

Archwires placed in the oral cavity for a long period of time will affect the surface roughness, which was initially smooth, and become rough due to the corrosion process (Misael & Haryadi, 2021). Increasing the surface roughness of orthodontic wires will affect tooth movement in orthodontic treatment. A rough wire surface will increase friction between the wire and the bracket, reducing the effectiveness of tooth movement. Because the corrosion event cannot be stopped, it needs to be controlled by adding an inhibitor substance (Misael & Haryadi, 2021; Mulyaningsih et al., 2019).

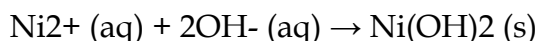
The use of an inhibitor substance, Robusta coffee bean extract, can be an effective solution (Misael & Haryadi, 2021; Mulyaningsih et al., 2019). The addition of a corrosion inhibitor substance from organic materials, namely Robusta coffee bean extract, shown in Figure.4 and Figure.5, shows a difference in surface roughness in each group. The decreased data in Table 1 and Table 2 shows a change in the average value of the surface roughness of stainless-steel orthodontic wires. This indicates that Robusta coffee bean extract (*Coffea canephora*) can reduce the surface roughness of stainless-steel orthodontic wires. Robusta coffee bean extract contains tannins, flavonoids, alkaloids, chlorogenic acids, and saponins (Chairgulprasert et al., 2019; Wigati et al., 2018). The content of phenolic compounds such as tannins, flavonoids, and alkaloids are compounds believed to bind to metals (Wulandari et al., 2023). These compounds can act as inhibitors because they meet organic compound inhibitors' characteristics, such as heteroatoms, polar groups, and free electron pairs that will bind to metals (Nasution et al., 2024). In addition to these compounds, chlorogenic acid compounds may also reduce surface roughness due to corrosion (Wei et al., 2018).

Flavonoids are essential in reducing the surface roughness of stainless-steel and CuNiTi orthodontic wires. Flavonoid compounds are believed to be able to prevent oxidative damage to metal surfaces. Flavonoids can modify cathodic and anodic polarization reactions on metal surfaces. This occurs by increasing electrical resistance on the metal surface, reducing the movement of corrosive ions, and slowing down electrochemical reactions that cause corrosion (Sudiarti et al., 2018; Ratnasari et al., 2023). Flavonoids are also rich in oxygen (O) and nitrogen (N) elements, which act as electron donors. This electron donation helps stabilize metal ions on the surface, thereby preventing the formation of positive metal ions that accelerate corrosion (Akbar, 2019).

Tannins can protect metals by forming a protective layer that prevents further damage. The structure of tannins consists of aromatic rings containing hydroxyl (OH) and carbonyl (C=O) groups. The hydroxyl group in tannins donates its lone pair of electrons to form a chelate bond with metal ions, producing metallic tannate compounds. This layer functions as a protective film evenly distributed over the entire metal surface, reducing roughness and increasing the metal's resistance to damage (Habibie & Palupi, 2014; Saputri et al., 2015).

The hydroxyl group (OH) of tannin will react with Ni metal ions released due to the corrosion process, forming an effective protective layer to reduce the

roughness of the metal surface. The following are reactions that can occur in Ni ions with hydroxyl groups in tannins and flavonoids (Symonowicz & Kolanek et al., 2012).



$\text{Ni}(\text{OH})_2$ is a stable complex compound that forms a passive layer on the metal surface of orthodontic wires (Jang et al., 2005). The layer adheres horizontally to create a structure on the metal surface and is oriented perpendicular to the metal surface, preventing the metal from interacting with the surrounding environment. Alkaloids also contribute to reducing the surface roughness of stainless-steel orthodontic wires. Alkaloid compounds can inhibit the rate of metal corrosion by forming a layer on the metal surface, thereby preventing direct contact between the metal and the corrosion agent (Zahra et al., 2019). This compound also contains the atomic elements N, O, P, and S, as in flavonoids, which have free electron pairs. Elements containing free electron pairs can later function as ligands forming complex compounds with metals, thus acting as a protective layer on the metal (Aripin & Purnawan, 2015).

The effect of other compounds in robusta coffee beans, such as chlorogenic acid, in reducing the surface roughness of wires is not fully understood. Chlorogenic acid is known to have antioxidant properties that can inhibit oxidation reactions. However, the mechanism of chlorogenic acid in reducing the surface roughness of orthodontic wires still requires further research (Husniati et al., 2021).

The mechanism of action of these compounds in reducing the surface roughness of orthodontic wires due to corrosion also depends significantly on the pH, time, and concentration of the compound in the solution. Therefore, it is necessary to regulate these parameters, such as neutralizing the pH of Robusta coffee bean extract, the frequency of soaking time, and the use of different extract concentrations to optimize the effectiveness of Robusta coffee beans as a corrosion inhibitor so that it can also help reduce the surface roughness of stainless-steel and CuNiTi orthodontic wires (Ishak et al., 2024).

The results of the surface roughness values in Table 1 show that T-2, using 2 g/L robusta coffee bean extract, has the lowest surface roughness value compared to the other groups. The difference in surface roughness values in each treatment group was influenced by the concentration of robusta coffee bean extract, which acts as an organic inhibitor. Based on the follow-up post-hoc LSD Test, as presented in Table 3 and Table 4, it is known that there is a significant difference between the control group without the addition of robusta coffee extract and T-2 with the addition of 2 g/L robusta coffee extract. This is because the higher the inhibitor concentration, the more metal surfaces are covered by a layer of complex compounds formed from the active compounds of the inhibitor. Increasing the concentration of the inhibitor will accelerate the formation of the passive layer so that the surface roughness of the wire becomes smoother due to a decrease in the corrosion rate (Siagian et al., 2010; Misael & Haryadi, 2021). Different results were found in other treatment groups, namely T-1 and T-3. This is because the concentration of the inhibitor that is too low or too high can reduce its effectiveness (Luvia et al., 2024).

The addition of Robusta coffee bean extract with a concentration of 1.5 g/L (T-1) showed that the surface roughness value changed slightly compared to the control group. Most of the surface roughness values in T-1 only decreased slightly, so the administration of Robusta coffee bean extract with a concentration of 1.5 g/L has not provided significant changes. This is likely due to the mild T-1 treatment, such as the low concentration used. Although there is a slight indication of improvement on some wire surfaces, in general, the effect of administering extract with a concentration of 1.5 g/L still does not provide significant results in reducing the surface roughness of stainless-steel and CuNiTi orthodontic wires (Hobbelink et al., 2015).

The results of the surface roughness values in Table 1 also show that T-3, using 2.5 g/L robusta coffee bean extract, has the highest surface roughness value. The results of the post-hoc LSD Test in Table 3 and Table 4 also show that there is no significant difference between the control group and T-3 (addition of 2.5 g/L robusta coffee extract). This occurs because although increasing the concentration of inhibitors can increase corrosion inhibition, its effectiveness has an optimal limit (Luvia et al., 2024). This is in accordance with Ulum's research (2018), namely that the addition of the right inhibitor concentration will result in more effective corrosion inhibition. To obtain optimal protection, the inhibitor concentration must be at a certain critical value, meaning the inhibitor concentration must be correct (Honawi & Iswanto, 2021). If the inhibitor is added more than its critical value, there will be a decomposition reaction again to the inhibitor layer that has been formed. The interaction between the inhibitor compound and the metal that exceeds the critical value will reach a saturation point, so the results will no longer be good (Fahrizal & Sutjahjo, 2019).

The group with a concentration of 2.5 g/L had a higher surface roughness value than the control group. This can happen because the inhibitor should form an even protective layer. However, giving extracts with high concentrations can cause an unstable and uneven layer, increasing the risk of micro-damage to the metal surface (Syahara et al., 2024; Yatiman, 2009). The research results also prove that adding organic inhibitors of Dayak onion leaf extract at a high concentration of 4% again increased the corrosion rate (Samosir & Oko, 2023).

The research results show that immersion of stainless-steel and CuNiTi orthodontic wire in Robusta coffee bean extract (*Coffea canephora*) has an effect. However, further research is needed with variations in extract concentration and different immersion durations to understand more deeply its impact on the roughness of the wire surface. In addition, SEM (Scanning Electron Microscope) testing is also needed to study the effect of corrosion on the roughness of the wire surface. In addition, it is used to observe the microstructure of metal at the nanometer level. This further study is expected to provide more comprehensive data to support efforts to improve the quality of orthodontic materials and understand the interaction of materials with the oral cavity environment.

CONCLUSIONS AND RECOMMENDATIONS

Robusta coffee bean extract (*Coffea canephora*) with a concentration of 1.5 g/L, 2 g/L can reduce the surface roughness of stainless-steel and CuNiTi orthodontic wires, which is thought to be caused by the content of flavonoid, tannin, and alkaloid compounds. Robusta coffee bean extract (*Coffea canephora*) with a concentration of 2 g/L is the most effective concentration in reducing the surface roughness of orthodontic wires made of stainless steel and CuNiTi.

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