Potency of Bilimbi Fruit (*Averrhoa Bilimbi L.*) Leaf Extract as Corrosion Inhibitors of Stainless Steel Orthodontic Wires

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Abstract

To determine the effects of Bilimbi fruit leaf (BL) extract on the corrosion rate of stainless steel orthodontic wires. A total of 60 stainless steel orthodontic wires (0.7 mm in diameter) were divided randomly into 4 groups (n=15): negative control group (control), 3% Bilimbi fruit leaf extract (B03), 6% Bilimbi fruit leaf extract (B06), and 10% Bilimbi fruit leaf extract (B10). Samples were immersed in artificial saliva and incubated at a temperature of 37°C for 7 days. Subsequently, the rate of corrosion was determined using a weight loss measurement method. The data were then analyzed using one-way analysis of variance (ANOVA) followed by least significant difference (LSD) post hoc test ($P < 0.05$). One-way ANOVA showed a significance P-value of < 0.05 ($P = 0.000$). Post-hoc LSD test also showed that there was a significant difference between control and treatment groups, in which the group immersed in 10% of BL extract had the lowest corrosion rate compared to the other two experiment groups. In addition, the 10% BL extract group had the highest percentage inhibition efficiency compared to the other two groups (79.84%). It can be concluded that Bilimbi fruit leaf extract can inhibit corrosion of stainless steel orthodontic wires. Ten percent of BL extract demonstrated a greater corrosion inhibition efficiency compared to 3% and 6% of the extract.

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Introduction

The principal purpose of orthodontic treatment is to correct malocclusion, to achieve appropriate occlusion and optimum dentofacial function.[1] The main components of an orthodontic appliance are brackets and archwires. An orthodontic archwire is a wire fitting to the dental arch that can be used within brackets as a reference of force in correcting the teeth misalignment.[2]

The orthodontic archwire is subjected to many stresses and variations in environment inside the oral cavity, such as masticatory force, temperature fluctuation, and effects of saliva and other ingested fluids. Several different combinations of the oral cavity environment may lead to corrosion on orthodontic wire components.[3] Stainless steel is biocompatible; thus, it is the commonly used wire in orthodontic treatments.[4] Unfortunately, stainless steel orthodontic wires are more prone to corrosion than nickel titanium wires.[5] Sodium, chloride, and potassium ions contained in saliva induce an acidic environment that degrades wire quality and speeds up stainless-steel corrosion.[6]

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Corrosion is defined as the degradation of wire quality caused by electrochemical reactions.[7] Orthodontic wire corrosion occurs because of the reaction between a wire and an acidic oral cavity environment. The chemical reaction of corrosion in an acidic liquid can be explained through this anodic reaction: $Fe \rightarrow Fe^{2+} + 2e^-$ followed by a cathodic reaction: $2H^+ + 2e^- \rightarrow H_2$.[8] Corrosion has harmful effects on human body, such as allergy, toxicity, carcinogenicity, and exposed dentin leading to hypersensitivity.[9] In addition, corrosion leads to an increase of wire–bracket friction and reduces the efficiency of orthodontic wires.[10]

Corrosion is not preventable, but it is controllable by applying an inhibitor. The use of inhibitors is the most effective method for protecting steel against corrosion, especially in acidic media. An inhibitor is a compound added in a low concentration that can slow down the corrosion rate.[10] Today, natural materials are preferable because they are more safe and affordable with minor side effects compared to chemical-based products.[11,12] Extensive previous studies have noted the potential of green corrosion inhibitors in preventing wire corrosion, such as *Jasminum sambac* extract.[13] Moreover, green inhibitors are biodegradable, inexpensive, and renewable.[14]

Bilimbi fruit (*Averrhoa bilimbi* L.) is a popular herbal plant in Indonesia and is commonly used in traditional medicine. The leaves of Bilimbi fruit are known to contain many nutrients that are useful for human health, which includes antioxidant, antimicrobial, anti-inflammatory, and antiulcer.[15] The chemical contents of Bilimbi fruit leaf are tannin, alkaloid, saponin, flavonoid, and phenol.[16] Prior research study also showed that tannin can be used as a natural inhibitor. Tannin can be used as a natural anticorrosion compound, replacing synthetic anticorrosion compounds.[17] Tannin acts as a corrosion inhibitor by forming a complex compound with iron ion (Fe^{2+}) within a stainless steel. Tannin can bind with Fe^{2+} ion because it is a macromolecular polyphenol.[18] The present research study aimed to determine the effects of Bilimbi fruit leaf extract on the corrosion rate of stainless steel orthodontic wires.

Methodology

This study was an experimental laboratory research that determines the effects of Bilimbi fruit leaf extract in various concentrations of 3%, 6%, and 10% on the corrosion rate of stainless steel orthodontic wires. Bilimbi fruit leaf extract was obtained using a maceration method. Wire samples for this study were stainless steel orthodontic wires (0.7 mm in diameter, 30 mm in length, American Orthodontics®, USA), bent into U shape. There were 60 samples and were divided into four groups: one control group and three treatment groups.

The initial sample weight was measured with a digital analytical balance and recorded in a measurement table. All samples in each group were then immersed in artificial saliva for 7 days. Through 7 days, all samples from the treatment groups were taken and immersed in a solution of Bilimbi fruit leaf extract. Each of the first, second, and third group was immersed in 3%, 6%, and 10% concentration of Bilimbi fruit leaf extract, respectively. Immersion was performed for 100 min.

After 7 days, all the samples were rinsed with distilled water and dried. Subsequently, the weight of the final samples was measured using a digital analytical balance. The corrosion rate of the wire was calculated with the following formula[19]:

$$C_R = \frac{W_b - W_a}{S.t} \qquad (1)$$

where C_R is the corrosion rate; W_b and W_a are the weight of specimens before and after exposure respectively, S indicates the total surface area and t is the time of exposure (hour).

Meanwhile, Inhibitor Efficiency (η in %) is calculated by following equation[2]:

$$\eta\,(\%) = \frac{C_{R(blank)} - C_{R(inh)}}{C_{R(blank)}} \times 100\% \qquad (2)$$

where η in % indicates the percentage of inhibitor efficiency; $C_{R(blank)}$ and $C_{R(inh)}$ are corrosion rate in the absence and presence of the inhibitor, respectively.

The data were then analyzed with a one-way analysis of variance (ANOVA) with normal distribution and homogeneity requirements and continued with post hoc least significant difference (LSD) test.

Results

The result shown in Figure 1 proves that the wires immersed in 10% of Bilimbi fruit extract had the lowest corrosion rate compared to others, reaching 0.013±0.0027 mg/cm^2/h.

The control group showed the highest corrosion rate (0.413±0.0572 mg/cm^2/h) compared to that of treatment groups. Figure 2 also showed that 1% Bilimbi fruit extract group had the highest percentage inhibition efficiency compared to that of the other two treatment groups (79.84±9.12%). Conversely, the minimum inhibition efficiency was observed in control (9.76±2.17%).

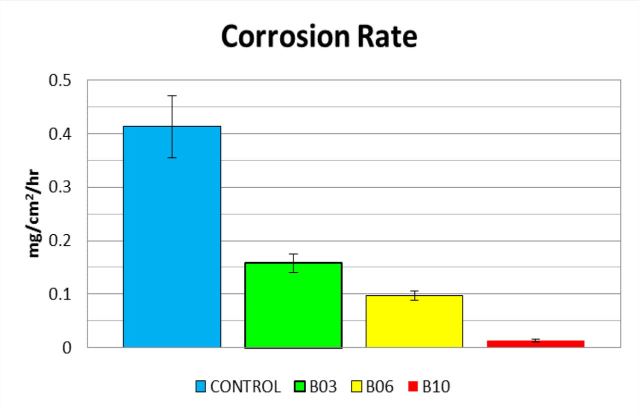

Figure 1. Intergroup comparison of stainless steel orthodontic wires corrosion rate between the control group and three treatment groups tested.
Values are presented as mean ± standard deviation; A: control group; B: group immersed in 3% concentration of Bilimbi fruit leaf extract; C: group immersed in 6% concentration of Bilimbi fruit leaf extract, and D: group immersed in 10% concentration of Bilimbi fruit leaf extract.

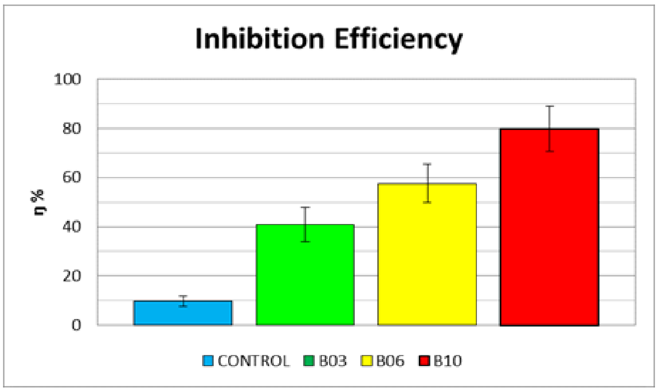

Figure 2. Variations of inhibition eficiency between four groups tested.
A: control group; B: group immersed in 3% concentration of Bilimbi fruit leaf extract; C: group immersed in 6% concentration of Bilimbi fruit leaf extract, and D: group immersed in 10% concentration of Bilimbi fruit leaf extract.

The results obtained were then analyzed using one-way ANOVA. To perform one-way ANOVA, data must be normally distributed and homogeneous. Normality test with Shapiro–Wilk test resulted in a significance *P*-value of 0.187 (> 0.05), indicating the data were normally distributed. Homoscedasticity test with Levene Statistic resulted in a significance *P*-value of 0.470 (> 0.05), indicating the data were homogenous. One-way ANOVA test could be performed as the data were normally distributed and homogeneous.

Table 1 shows that there was a significant difference in the corrosion rates (*P* < 0.05) among all the groups; thus, there was a significant difference among the types of treatment. The difference among the treatment groups could be determined with post hoc LSD test. The results of *post-hoc* LSD are provided in Table 1, as well.

Group	N	Significance *	*P*-value		
			B03	B06	B10
Control	15	*P*=0.000*	0.013*	0.000*	0.000*
B03	15			0.069	0.007*
B06	15				0.298
B10	15				

Table 2. One way Anova and Post-hoc LSD test results.
significant (*) (P < 0.05)

Data are significantly different if the significance *P*-value is <0.05. Table 2 shows that there was a significant difference between control groups and immersion in 3%, 6%, and 1% of leaf extract in the treatment groups. There was also a significant difference between the treatment groups of immersion in 3% and 10% of the extract. No significant difference was shown between treatment groups of immersion in 3% and 6% of extract, as well as between the treatment groups of immersion in 6% and 10% of the extract.

Discussion

This research study was conducted to examine the corrosion rates of stainless steel orthodontic wires in artificial saliva with different concentrations of Bilimbi fruit leaf extract. The results indicated that there is a significant difference in the effects of Bilimbi fruit leaf extract concentration on the corrosion rate of stainless steel orthodontic wires. The results affirmed that the concentration of Bilimbi fruit leaf extract was influential in slowing down the corrosion rates of stainless steel orthodontic wires. The highest average rate of corrosion was identified in samples of the control group, while the lowest average rate of corrosion was identified in the treatment group of immersion in 10% of Bilimbi fruit leaf extract. These results prove that the higher the Bilimbi fruit leaf extract concentration, the better the corrosion-inhibiting ability.

One-way ANOVA and *post-hoc* test indicated that there was a significant difference among experimental groups. Thus, Bilimbi fruit leaf extract is influential in slowing down the corrosion rate of stainless steel orthodontic wires was proven, with 10% concentration of Bilimbi fruit leaf extract showing a greater inhibitory effect than 3% and 6% concentration. In other words, the higher the concentration of Bilimbi fruit leaf extract, the better the corrosion inhibition efficiency. The decrease in the average rate of corrosion in stainless steel orthodontic wires was caused by active compounds in Bilimbi fruit leaf extract. Several chemical compounds are present in the Bilimbi fruit leaf such as tannin, alkaloid, saponin, flavonoid, and phenol.[14] Several research studies identified that tannin can be used as a natural inhibitor. Tannin acts as a corrosion inhibitor by forming a complex compound with iron ion (Fe), which forms a thin protective layer on the surface of stainless steel orthodontic wires. This thin layer prevents corrosive chloride ions in the saliva from penetrating the surface of stainless steel wire.[8]

According to the inhibitory mechanism, Fe ions in stainless steel wire will bind with the active compound within an inhibitor and form a complex bond. This complex will produce a thin layer on the surface of wire and restrict the direct contact of wire with a corrosive medium.[19] This research result is supported with previous research by Murthy and Vijayaragavan[8] about corrosion inhibitor: the higher the concentration of corrosion inhibitor, the lower the rate of corrosion. Increasing inhibitor concentration causes more inhibitor molecules to bind on the surface of wire; therefore, more inhibitor molecules are adsorbed by the wire and form a tighter complex. This complex protects the wire surface from corrosive solution.

Results of research also shows that the anticorrosive effect of Bilimbi fruit leaf extract can slow down the corrosion rates, even if it is used as mouthwash. Daily mouthwash is done twice for an average of 1 min. On average, orthodontic treatment lasts for about 23.12 months.[20] The accumulation of mouth washing time during orthodontic appliance usage, divided by research time, resulted in 100 min. Hence, orthodontic wire immersion in an extract was done for 100 min. In reality, the duration of immersion could be too extensive, and therefore, a research about proper immersion time is required.

A further research about Bilimbi fruit leaf extract application in various concentrations and its use as dental appliances cleansing wipes is required. However, before its clinical application, toxicity tests for Bilimbi fruit leaf extract needs be done to establish its other effects on oral cavity and general health in humans.

Conclusion

Bilimbi fruit leaf extract could inhibit the rate of corrosion of stainless steel orthodontic wires. Furthermore, 10% of the extract showed a greater effect in preventing corrosion of stainless steel orthodontic wires compared to 3% and 6% of the Bilimbi fruit leaf extract.

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