The Potential Of Avocado Seed Extract (*Persea Americana*) In Inhibiting The Release Of Metal Ions In Cuniti And Stainless Steel Based Orthodont Wire

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Abstract.

The release of ions is the initial stage of the corrosion process in an orthodontic wire. Continuous release of ions can reduce the effectiveness and performance of the orthodontic wire. Continuous release of ions in CuNiTi orthodontic wire can change the properties of the wire and trigger hypersensitivity reactions, also in stainless steel orthodontic wire which experiences continuous release of ions can reduce its stiffness. The tannin in avocado seeds is useful as a corrosion inhibitor it can inhibit the release of ions because they are able to bind with metal ions and form a passive layer also able to bind with Fe ions in stainless steel orthodontic wires to form a passive surface layer which is able to inhibit the release of ions when the corrosion process occurs. The aim of this research is to determine the effect of avocado seed extract as a corrosion inhibitor on the release of metal ions from CuNiTi and stainless steel orthodontic wires. Rectangular CuNiTi and stainless steel orthodontic wires measuring 0.017 x 0.025 inches were taken in 3 groups (1 control group soaked in artificial saliva and 2 treatment groups soaked in avocado seed extract). The samples were soaked in avocado seed extract with a concentration of 1.5 g/L and 2 g/L for 7 days. To see the release of ions, an X-Ray Fluorescence test is carried out. In CuNiTi orthodontic wire from the one way ANOVA test showed that there was a significant difference between the control group and all treatment groups on Cu, Ni and Ti ions. The Post Hoc LSD test showed that there were significant differences between the control group, treatment group 1 and treatment group 2 in Cu, Ni and Ti ions with a p value. In stainless steel orthodontic wire, the one way ANOVA test showed that there was a significant difference between the control group and all treatment groups in Fe and Ni ions but not significant in Cr ions in the ion release test with a p value <0.05. The Post Hoc LSD test showed that there were significant differences between the control group, treatment group 1 and treatment group 2 in Fe and Ni ions with a p value <0.05. Providing avocado seed extract with tannin content at concentrations of 1.5 g/L and 2 g/L can inhibit the rate of ion release in CuNiTi and stainless steel orthodontic wires due to the corrosion process.

Keywords: *Avocado seed extract, stainless steel orthodontic wire, CuNiTi othodontic wire,and ion release.*

I. INTRODUCTION

Tooth movement in orthodontics is brought about by orthodontic archwires, which generate the biomechanical forces, transmit these forces via brackets to bring about tooth movement. Stainless steel (SS) and nickel-titanium (NiTi) wires are the most commonly used orthodontic archwires these days [1]. The CuNiTi wire, composed of 50.7% Nickel, 42.4% Titanium, and 6.9% Cuprum, exhibits enhanced material strength, greater elasticity, generates a more consistent yet gentle force, and demonstrates increased resistance to permanent deformation. [2] [3]. Stainless steel wire, with its inherent rigidity attributed to a substantial 71% iron (Fe) content, is employed as an orthodontic appliance to act as a brace for tooth movement. Additionally, this wire contains other essential ions, including 18% chromium (Cr) and 8% nickel (Ni) [4]. In the oral cavity, wires made of CuNiTi and stainless steel come into contact with saliva, which serves as an electrolytic medium, initiating electrochemical reactions that can alter the performance of the wires. During the corrosion process of CuNiTi wire in the oral cavity, the release of ions occurs, leading to changes in the physical properties of CuNiTi wires and a reduction in the efficiency of tooth movement during treatment. Additionally, the nickel (Ni) released from CuNiTi can also induce hypersensitivity reactions [5]. In stainless steel wires, the release of iron (Fe) ions also occurs. The presence of iron contributes to the rigidity of stainless steel wires, enabling them to facilitate bodily tooth movement. [6].

The excessive release of iron (Fe) ions over an extended period can have adverse effects on stainless steel orthodontic wires, particularly concerning their stiffness properties. Insufficient stiffness may render the wire more flexible, disrupting the intended function of the rigid stainless steel wire in tooth movement. The released ions contribute to surface degradation and a reduction in wire mass, potentially leading to brittleness if the process persists over an extended duration.[7]. Additionally, the release of chromium (Cr) and nickel (Ni) ions from stainless steel wires serves as an indicator of corrosion occurrence [6]. Corrosion that occurs on stainless steel orthodontic wires needs to be inhibited as it can lead to a reduction in both the strength and quality of the wire. [8]. Hence, efforts are required to inhibit corrosion, and this can be achieved through the use of inhibitors.The extract from avocado seeds (*Persea americana*) is recognized as a potential corrosion inhibitor. Within the extract, ethanol serves as a solvent, and it contains tannin compounds at a concentration of 0.2044%.[9]. Tannins can impede the corrosion rate on metal surfaces by acting as a coating agent and forming a passive layer. The passive layer is a condition in which the metal loses its reactivity, thereby enhancing resistance to ion release [10].

II. METHODS

This study employs an experimental laboratory design with a pretest-posttest control group design. The samples utilized consist of CuNiTi and stainless steel orthodontic wires with a rectangular cross-section measuring 0.017 x 0.025 inches, cut into 2 cm lengths. The sample size for each wire type is 12 pieces, divided into three groups: one control group immersed in artificial saliva and two treatment groups immersed in avocado seed extract with concentrations of 1.5 g/L and 2 g/L. Avocado fruits of the butter avocado variety were obtained from the Sidorejo Avocado Plantation, Jember. The criteria for selecting avocado fruits included mature avocados with a weight ranging from 200 to 300 grams. The process of extracting the avocado seed involved peeling and thoroughly cleaning the seeds. Subsequently, the seeds were thinly sliced for easier drying, and the slices were then dried in an oven at 40°C. Once dried, the avocado seed slices were blended into powder. The powder was then subjected to extraction using a solvent, namely 95% ethanol, with a ratio of 1:10. 100 grams of avocado seed powder were weighed and placed in a jar, followed by maceration with 1000 mL of ethanol. The mixture was stirred gently, left to macerate for 24 hours, and then filtered to obtain the extract from the maceration process.

Subsequently, a remaceration process was conducted using 1000 mL of ethanol solvent, followed by another 24-hour period of settling. The extract was then filtered again to obtain the extract resulting from the remaceration. The extracts from maceration and remaceration were combined and the solvent was evaporated using a rotary evaporator. The evaporated extract was further dried in an oven at 60°C until a concentrated extract was obtained [11]. The outcome of the extract preparation process yielded a concentrated extract that needed dilution. The extract was weighed using an analytical balance, followed by the addition of artificial saliva in a quantity of 1000 mL, with concentrations in each treatment group set at 1.5 g/L and 2 g/L. The composition of the artificial saliva in this study adhered to the Afnor method, including Na2HPO4 at 0.26 g/L, KSCN at 0.33 g/L, NaCl at 6.0 g/L, KH2PO4 at 0.20 g/L, KCl at 1.20 g/L, and NaHCO3 at 1.50 g/L. The pH of the artificial saliva was then balanced and controlled using HCl until it reached the specified pH of 6.8. [12]. According to the research, the average gargling time with mouthwash was one minute, with an average frequency of twice a day, both in the morning and evening. [13]. The peak occurrence of corrosion in orthodontic wires within the oral cavity is observed on the seventh day. [10].

In this study, immersion in avocado seed extract, dissolved in artificial saliva, was performed for one minute with a frequency of twice a day until the seventh day [14]. Each sample was placed into a sterile petri dish and labeled according to its group: Group (K) for the control, (P-1) for a concentration of 1,5 g/L, and (P-2) for a concentration of 2 g/L. The control group samples were immersed in artificial saliva within an incubator for 7 days, aligning with the average peak of corrosion on orthodontic wires. In the treatment groups, all samples were placed into petri dishes containing a solution of artificial saliva and avocado seed extract for 1 minute. After 1 minute, the samples were rinsed with aquades and returned to petri dishes containing artificial saliva before being placed back into the incubator. Immersion of the samples in the treatment solution occurred twice a day, in the morning and evening, for 7 days. The XRF method was employed to analyze ions released from CuNiTi and stainless steel orthodontic wires during the corrosion process, by examining the initial and final contents of CuNiTi and stainless steel wires after treatment.

III. RESULT AND DISCUSSION

The research data on the effect of avocado seed extract (*Persea americana*) on the release of metal ions from CuNiTi orthodontic wires, as determined through X-Ray Fluorescence (XRF) testing, is presented in the table below.

Table 3.1. Average Research Results of Ion Release and Percentage of CuNiTi Ion Release

Ion	Initial Content	Final Content (Average)			Ion Release	Percentage Release of Ion
		C	T1	T2		
Cu	6,19 %	2,65 %			3,54 %	57,19 %
			4,87 %		1,32 %	21,32 %
				5,97%	0,22 %	3,55 %
Ni	47,6 %	12,13%			35,47 %	74,51%
			39,47 %		8,13 %	17,08 %
				47,35 %	0,25 %	0,52 %
Ti	41,0 %	14,10 %			26,9 %	65,6 %
			38,37 %		2,63 %	6,41 %
				40,52 %	0,48 %	1,17 %

Information:

(C) : Control (wire soaked with artificial saliva)

(T1) : Treatment 1 (wire soaked with avocado seed extract at a concentration of 1.5 g/L)

(T2) : Treatment 2 (Wire soaked with avocado seed extract at a concentration of 2.0 g/L)

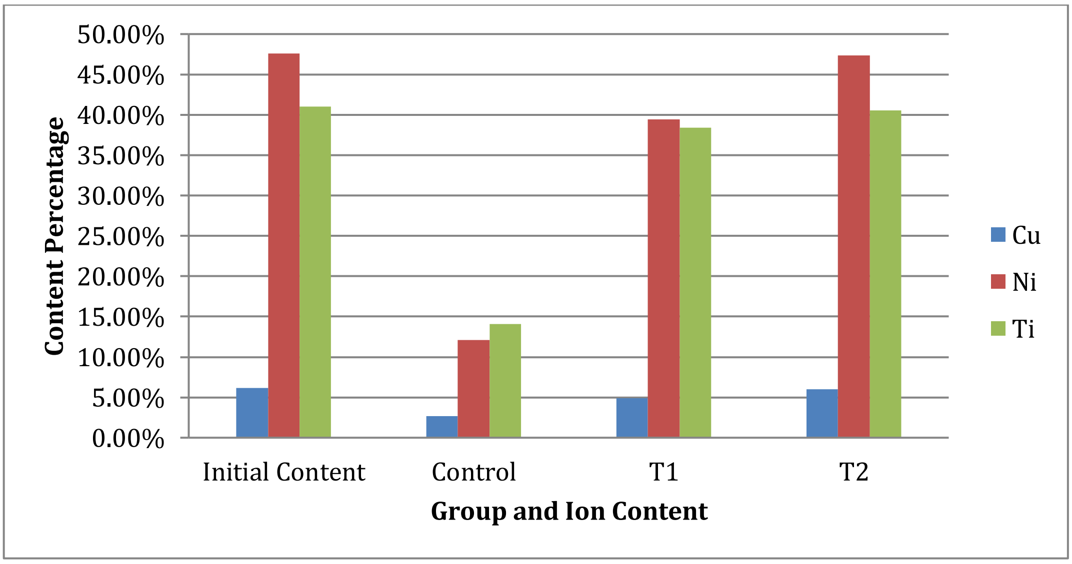

Fig 1. Bar Chart of Average Percentage of Cu, Ni and Ti Ion Content

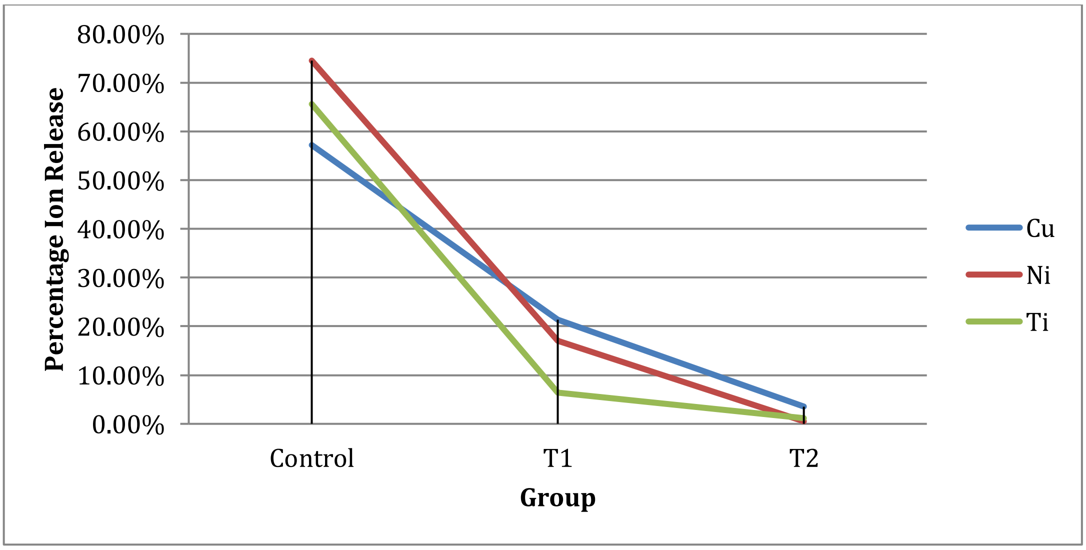

Fig 2. Line Chart of Percentage Release of Cu, Ni and Ti Ions

Table 3.1 and Figure 1 illustrate the initial and final content of CuNiTi wires in each control group, treatment 1, and treatment 2. The research data presented in Table 3.1 indicates that the highest ion release is observed in the control group, followed by treatment group 1 and treatment group 2. From the data, it can be inferred that the remaining ion values tend to increase and approach the initial content with a higher concentration of added extract.Based on the data in Table 3.1, the ion release difference is calculated as the result obtained from subtracting the initial content from the values in each control group, treatment 1, and treatment 2. Meanwhile, the ion release percentage is calculated from the difference in ion release divided by the initial content and multiplied by 100%.

The research results in Table 3.1 and Figure 2 indicate that the control group has the highest percentage of ion release, with Ni ions being the most released, followed by Ti and Cu ions. Treatment group 1 shows the highest percentage of Cu ion release, followed by Ni and Ti ions. On the other hand, treatment group 2 demonstrates the least average ion release, approaching the initial content, with the ion release percentage indicating that Cu ions are the most released, followed by Ti and Ni ions.Research data regarding the influence of avocado seed extract (*Persea americana*) on the ion release of orthodontic wires made of stainless steel is provided in the table below.

Table 3.2. Average Ion Release of Stainless steel Orthodontic Wires from XRF Test

Ion	Initial Content	Final Content (Average)			Ion Release	Percentage Release of Ion
		C	T1	T2		
Fe	71 %	66,275 %			4,725%	6,65%
			67,66 %		3,34%	4,7%
				68,95 %	2,05%	2,88%
Cr	18 %	16,9 %			1,1%	6,11%
			17,4 %		0,6%	3,33%
				17,52 %	0,48%	2,66%
Ni	8 %	7,07 %			0,93%	11,625%
			7,44 %		0,56%	7%
				7,72 %	0,28%	3,5%

Information:
(C) : Control (wire soaked with artificial saliva)
(T1) : Treatment 1 (wire soaked with avocado seed extract at a concentration of 1.5 g/L)
(T2) : Treatment 2 (Wire soaked with avocado seed extract at a concentration of 2.0 g/L)

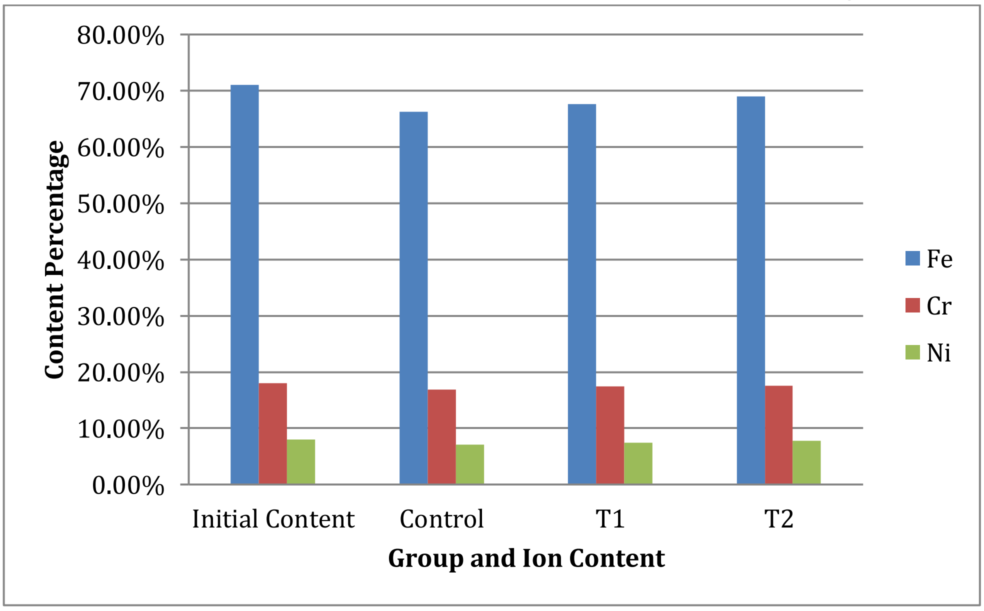

Fig 3. Average chart of ion release in Stainless steel orthodontic wire

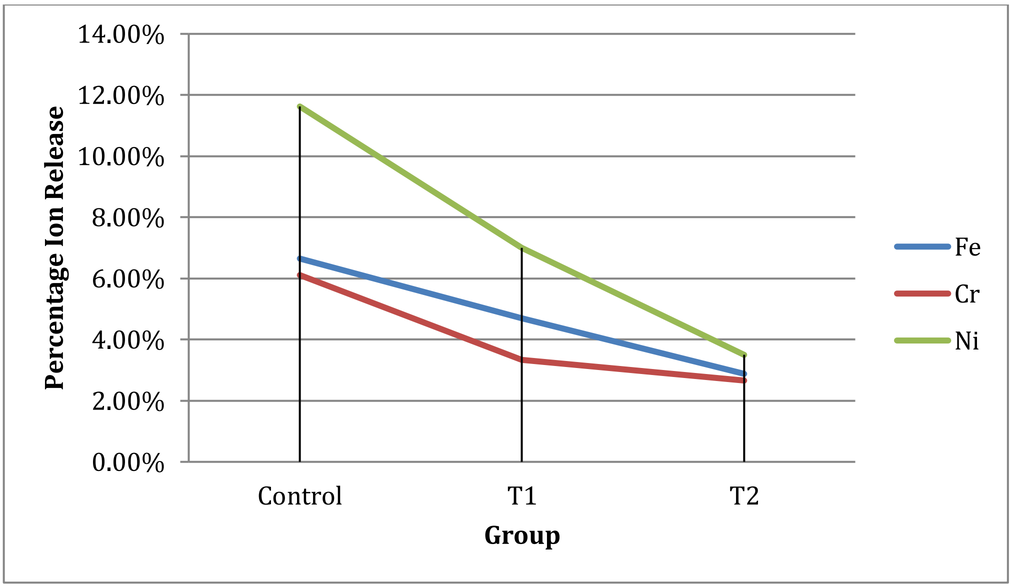

Fig 4. Line chart of the average percentage of ion release in Stainless steel orthodontic wire.

Based on the data in Table 3.2, the ion release difference is calculated as the result obtained from subtracting the initial content from the values in each control group, treatment 1, and treatment 2. Meanwhile, the ion release percentage is calculated from the difference in ion release divided by the initial content and multiplied by 100%.The research data presented in Table 3.2 indicates that the highest ion release is observed in the control group, followed by treatment group 1 and treatment group 2. In Table 3.2 and Figure 4, the control group exhibits the highest percentage of ion release, with Ni ions being the most released, followed by Fe and Cr ions.

Treatment group 1 shows the highest percentage of ion release, with Ni ions being the most released, followed by Fe and Cr ions. On the other hand, treatment group 2 demonstrates the least average ion release, approaching the initial content, with the ion release percentage indicating that Ni ions are the most released, followed by Fe and Cr ions. From the data, it can be inferred that the remaining ion values tend to increase and approach the initial content with a higher concentration of added extract.Based on the results of normality and homogeneity tests, it is determined that the data are normally distributed and homogenous, allowing for the continuation of parametric statistical testing using One-Way ANOVA. The results of the parametric statistical test One-Way ANOVA can be observed in the table below.

Table 3.3. One Way ANOVA test results for CuNiTi

Ion	*p-value*
Cu	0.000*
Ni	0.000*
Ti	0.000*

$(p < 0.05)$ = There are differences between groups

The results of the One-Way ANOVA analysis in Table 3.3 indicate a significant difference among the four test groups (between each treatment group compared to the control group and between the treatment groups themselves) with a significance value of $p = 0.000$ $(p < 0.05)$. This suggests that there is a difference in the mean metal ion levels in CuNiTi orthodontic wires between the group without corrosion inhibitor and the groups treated with avocado seed extract at concentrations of 1.5 g/L and 2 g/L. This indicates an influence of avocado seed extract on the release of metal ions from CuNiTi orthodontic wires. Therefore, it can be concluded that avocado seed extract can inhibit corrosion and reduce the release of metal ions from CuNiTi wires.Subsequently, a further test was conducted, namely the Post-hoc LSD test, aiming to determine significant differences between one group and another. The results of the Post-hoc LSD test can be seen in the table below.

Table 3.4. Post Hoc LSD test results for CuNiTi

Ion	Group	Group	*Mean Difference*	*P-value*
Cu	C	T1	-2.21500*	0,000*
		T2	-3.32000*	0,000*
	T1	C	2.21500*	0,000*
		T2	-1.10500*	0,000*
	T2	C	3.32000*	0,000*
		T1	1.10500*	0,000*
Ni	C	T1	-27.34500*	0,000*
		T2	-35.22000*	0,000*
	T1	C	27.34500*	0,000*
		T2	-7.87500*	0,000*
	T2	C	35.22000*	0,000*
		T1	7.87500*	0,000*
Ti	C	T1	-24.79250*	0,000*
		T2	-26.94250*	0,000*
	T1	C	24.79250*	0,000*
		T2	-2.15000*	0,000*
	T2	C	26.94250*	0,000*
		T1	2.15000*	0,000*

Significant (*) ($p < 0,05$) = there are significant differences

From the results of the Post-hoc LSD test in Table 3.4, it can be concluded that there is a significant difference between the control group and all treatment groups, as indicated by significance values less than 0.05 ($p < 0.05$). The data also infer a significant difference between each treatment group and the control group, for both Cu, Ni, and Ti ions, with significance values less than 0.05 ($p < 0.05$).The protein data obtained from the research results were then analyzed using a One-Way ANOVA test. Before conducting the One-Way ANOVA test, it is essential for the data to be normally distributed and homogenous. Therefore, preliminary analysis tests were conducted, including the normality test using the Shapiro-Wilk test and the homogeneity test using Levene's Test. The results of the Shapiro-Wilk normality test and Levene's homogeneity test indicate that all data are normally distributed and homogenous with $P > 0.05$.The difference in ion release in stainless steel orthodontic wires was analyzed using the One-Way ANOVA test, as the prerequisites for the test were met, with normal and homogenous data distributions. The One-Way ANOVA test was performed to determine whether there is a significant difference between data groups. The results of the One-Way ANOVA test can be seen in Table 3.5.

Table 3.5. One Way ANOVA Stainless steel test results

Ion	*P-value*
Fe	0.000*
Cr	0.087*
Ni	0.001*

Significant (*) ($P < 0.05$) = There are differences between groups

The data presented in Table 3.5 indicates significant differentiation for Fe and Ni ion release with $P < 0.05$. However, for Cr ion release, the result is $P > 0.05$, specifically 0.087. This suggests that there is no significant differentiation in the average release of Cr ions in stainless steel orthodontic wires between the control and treatment groups. Further analysis to assess the average differences in Fe and Ni ion release is necessary, and this can be achieved through the Post Hoc LSD Test. The results of the Post Hoc LSD Test are presented in Table 3.6.

Table 3.6. Post Hoc LSD test results for Fe and Ni ions in Stainless steel

Ion	Kelompok	Kelompok	*Mean Difference*	*P-value*
Fe	C	T-1	1.38750	0.000*
		T-2	2.67500	0.000*
	T-1	C	1.38750	0.000*
		T-2	1.28750	0.000*
	T-2	C	2.67500	0.000*
		T-1	1.28750	0.000*
Ni	C	T-1	0.36750	0.007*

	T-2	0.65000	0.000*
T-1	C	0.36750	0.007*
	T-2	0.28250	0.025*
T-2	C	0.65000	0.000*
	T-1	0.28250	0.025*

Significant (*) ($P < 0.05$) = There are significant differences

Data in tables 4.3 and 4.4 indicate significant differences, with significant differences highlighted by significance values less than 0.05 ($p < 0.05$) for both Fe and Ni ion release data in each group—namely, between the control group and treatment group 1, the control group and treatment group 2, as well as treatment group 1 and treatment group 2.Ion release difference is calculated by subtracting the initial content from the values in each control group, treatment group 1, and treatment group 2. Meanwhile, the ion release percentage is calculated by dividing the difference in ion release by the initial content and multiplying by 100%.In Table 3.1 and Figure 1, the ion content in CuNiTi wires is shown for the initial and final content in the control group, treatment group 1, and treatment group 2. After undergoing XRF testing, CuNiTi wires have an initial ion content of Cu 6.19%, Ni 47.6%, and Ti 41.0%. The control group shows the least final content with Cu 2.65%, Ni 12.13%, and Ti 14.10%. Treatment group 1 demonstrates final ion content of Cu 4.87%, Ni 39.47%, and Ti 38.37%. Meanwhile, treatment group 2 shows final ion content approaching the initial content with Cu 5.97%, Ni 47.35%, and Ti 40.52%. From the results above, it can be concluded that treatment group 2 has ion content closest to the initial content of CuNiTi wire. This is influenced by the tannin content in avocado seeds, which can function as a corrosion inhibitor and ion release inhibitor [15].
The control group in the CuNiTi wire, as shown in Table 3.1, indicates that Nickel has a higher percentage of release compared to Titanium and Cuprum. This is attributed to the different metals having distinct tendencies for oxidation due to variations in their electron structures. In the voltaic series, Titanium is positioned to the left of Nickel and Cuprum, indicating that Titanium has a smaller electrode potential compared to Nickel and Cuprum.

The tendency to oxidize (ionize) is measured by the electrode potential expressed in volts or millivolts. The more negative the electrode potential, the easier a specific metal undergoes ionization and oxidation, making it more susceptible to stains and corrosion. Conversely, the more positive the electrode potential, the less vulnerable the metal is to stains and corrosion. If two pure metals are immersed in an electrolyte and connected with an electric conductor to form a galvanic cell, the metal with the lower electrode potential (more negative) becomes the anode and undergoes oxidation (loses ions) [16]. Titanium is the most reactive metal and undergoes ion release first; however, titanium has the capability to form a highly stable oxide passive layer (TiO2) [17]. The stable oxide passive layer of titanium enhances its resistance to corrosion and ion release. This phenomenon results in a higher release of nickel followed by titanium and cuprum.The research data presented in Table 3.1 and Figure 2 also demonstrate that avocado seed extract proves effective in inhibiting the release of metal ions from CuNiTi orthodontic wires. In Table 3.1, avocado seed extract with concentrations of 1.5 g/L and 2 g/L exhibits the ability to inhibit ion release in CuNiTi orthodontic wires. The percentage of ion loss with 1.5 g/L extract is 21.32% for Cu, 17.08% for Ni, and 6.41% for Ti. Meanwhile, the percentage of ion loss with 2 g/L extract is 3.55% for Cu, 0.52% for Ni, and 1.17% for Ti. From these findings, it is evident that the 1.5 g/L concentration of extract is effective in inhibiting the release of Titanium ions, while the release of other metal ions, namely Nickel and Cuprum, begins to be effectively inhibited with the addition of extract at a concentration of 2 g/L. This is attributed to the fact that, although titanium is the most reactive metal and undergoes ion release first, it can form a highly stable oxide passive layer (TiO2) [17].

In Table 3.2, which represents the average metal ion release data from stainless steel orthodontic wires tested using XRF, the initial content of Fe ions is found to be 71%, Cr ions at 18%, and Ni ions at 8%. The control group exhibits the lowest average content, with Fe ions at 66.275%, Cr ions at 16.9%, and Ni ions at 7.07%. Treatment group 1 shows Fe ions at 67.66%, Cr ions at 17.4%, and Ni ions at 7.44%. Meanwhile, treatment group 2 demonstrates average ion content closest to the initial levels of stainless steel orthodontic wire ions, with Fe ions at 68.95%, Cr ions at 17.52%, and Ni ions at 7.72%. This result is attributed to the presence of tannins in avocado seed extract, which can bind with metal ions from stainless steel orthodontic wires and form a passive surface layer as a protective coating, inhibiting the release of metal ions from stainless steel orthodontic wires.Metals exhibit varying tendencies for oxidation due to differences in their electron structures. The propensity for oxidation or ionization can be measured using electrode potential. The more negative the electrode potential, the more susceptible a metal is to oxidation and corrosion. Conversely, the more positive the electrode potential of a metal, the lower its vulnerability to oxidation and corrosion [16]. Chromium is positioned to the far left in the periodic table and voltaic series when compared to iron (Fe) and nickel (Ni). Therefore, chromium is a metal with the most negative electrode potential and is susceptible to corrosion. This susceptibility may arise due to prolonged exposure of the samples to air during the extended testing period, leading to a higher release of Cr ions compared to Fe and Ni ions.

This is evident in the data of one sample (P-2), where the reduction of Cr ions is more significant than in sample P-1. This factor contributes to the non-significant results for Cr ion in the one-way ANOVA test. [18]. This can be interpreted as tannins in avocado seed extract having the ability to bind with Fe and Ni metals and effectively inhibit ion release. Tannins form complex compounds with iron ions, creating Fe-tannate complexes that act as a barrier to direct contact with stainless steel. Tannins are capable of forming complex compounds with Fe^(2+), leading to the formation of ferro-tannate, which can readily oxidize to ferri-tannate in the presence of oxygen. Additionally, tannins can react directly with Fe^(3+) ions to produce ferri-tannate. Due to its reducing properties, tannins can also reduce Fe2O3 to Fe^(3+) ions. Ferro-tannate can undergo direct reduction upon contact with O2 and H2O, resulting in ferri-tannate [19]. The addition of corrosion inhibitors has proven to be an efficient approach in effectively controlling corrosion. Corrosion inhibitors involve adding substances to a solution to minimize metal corrosion. [20]. The utilization of affordable, non-toxic, readily available, and environmentally friendly inhibitors is highly desirable, with natural materials offering the most promising solution. [21]. The avocado seed extract, enriched with tannin compounds known for their natural inhibitive properties, has been selected as a corrosion inhibitor [9]. Corrosion inhibitors operate through the adsorption mechanism of molecules and ions on the metal surface. The absorption mechanism of organic corrosion inhibitors on the metal surface begins with the displacement of water molecules adsorbed on the metal surface by inhibitor molecules.

This is because the water tension is higher than the inhibitor's surface tension, resulting in an increased surface attraction of the metal to the inhibitor compared to water. Subsequently, the inhibitor binds to metal ions formed on the metal surface, forming a complex metal-inhibitor compound. This compound is expected to be capable of restraining and limiting the direct interaction between the metal and the corrosive solution. [22]. Tannins can inhibit corrosion and ion release on metal surfaces by acting as a coating agent and forming a passive layer. A passive layer is a state where the metal loses its reactivity, thereby enhancing resistance to ion release [10]. Tannins possess the property of solubility in water or alcohol due to their high phenol content, which contains hydroxyl (OH) groups capable of binding heavy metals. [23]. The tannin molecule contains several hydroxyl and carbonyl groups on the aromatic ring, which contains oxygen atoms capable of donating their free electron pairs, forming chelates with metal cations. Proença et al. (2022) explained that tannin's corrosion inhibition ability arises from the reaction of polyphenol subunits in tannin molecules with metal ions, forming a network of cross-linked bonds known as metallic-tannates. This compound acts as a barrier to water, preventing direct contact with the metal and thus serving as a passive layer. [24]. The carbonyl group acts as an electron donor on the metal surface, binding with inhibitor molecules, leading to an increase in electron density. This elevation in electron density results in corrosion inhibition [25]. The data analysis using the one-way ANOVA test indicates a significant difference among groups with a significance value of 0.000 ($p < 0.05$) for Cu, Ni, and Ti ions. Further, the Post-hoc LSD test concluded that there is a significant difference between the groups, as indicated by significance values less than 0.05 ($p < 0.05$) for Cu, Ni, and Ti ions.

These research findings align with a prior study by Hasna (2023), who investigated the corrosion rate control of CuNiTi metal through the addition of avocado seed extract as a natural inhibitor. The study showed that avocado seed extract can effectively reduce the corrosion rate. [15]. According to Dulzamirki (2023), it is also proven that avocado seed extract at a concentration of 2 g/L is effective in inhibiting the corrosion rate on stainless steel-based orthodontic wires, using the weight loss calculation method. Higher concentrations of avocado seed extract result in a decrease in both corrosion rate and ion release [26]. The continuous release of ions from orthodontic wires can lead to a reduction in the strength and quality of the wire. [8]. The occurrence of ion release also prolongs orthodontic treatment due to the diminished quality of the wire [27]. The ion release process also affects the flexibility of the wire. Wire flexibility is the wire's ability to return to its original position after being moved. This flexibility influences the force applied to shift teeth during orthodontic treatment. The greater the release of orthodontic metal ions, the lower the wire flexibility, which, in turn, affects the duration of orthodontic treatment [28]. In stainless steel orthodontic wires, there is a protective layer or coating, such as a protective barrier, capable of shielding the stainless steel wire from direct contact with the electrolyte medium, such as saliva in the oral cavity. This protective layer provides water and chemical resistance, making the stainless steel wire more resistant to corrosion and ion release. In contrast, non-coated wires without this protective layer are more prone to metal ion release, initiating the corrosion process. Therefore, the immersion results of the control group indicate that the released ions in CuNiTi orthodontic wires are higher compared to those in stainless steel wires.[8] [29].

IV. CONCLUSION

From the research results, it can be concluded that the addition of avocado seed extract at a concentration of 1.5 g/L is effective in inhibiting the release of Titanium ions. Meanwhile, the release of other metal ions, namely Cuprum and Nickel, starts to be effectively inhibited with the addition of extract at a concentration of 2 g/L in CuNiTi orthodontic wires. On the other hand, the addition of avocado seed extract to stainless steel orthodontic wires can significantly inhibit the release of Fe and Ni metal ions at a concentration of 2 g/L. Therefore, the avocado seed extract with a concentration of 2 g/L is the most effective concentration in inhibiting the release of metal ions from both CuNiTi and stainless steel orthodontic wires, as evidenced by the remaining ions approaching the initial content of each CuNiTi and stainless steel wire.

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