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Impact of the Different Application Times of Natural Antioxidants on Shear Bond Strength of Resin Composite to Bleached Enamel Surface

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Abstract

Natural antioxidants present a viable option for instant bonding by counteracting free radicals and reinstating composite to bleached enamel adhesion. The aim of this study was to evaluate the impact of varying application durations (10, 15, and 20 minutes) of two types of natural antioxidants ethanolic extracts (Moringa oleifera and Salvadora persica) on Shear Bond Strength (SBS) of resin composite to bleached enamel. Methods: the 108 extracted premolar teeth were randomly allocated into nine groups: unbleached enamel (control), bleached enamel with delayed bonding (one-week post bleaching), and six groups treated with Moringa oleifera or Salvadora persica extracts for durations of 10, 15, or 20 minutes. The shear bond strength was evaluated with a universal testing machine, failure mode analysis done by using a stereomicroscope. Results: Bleaching significantly diminished shear bond strength (SBS) in comparison to unbleached enamel (6.39 MPa vs. 26.22 MPa) at ($p \leq 0.05$). The delayed bonding group demonstrated partial SBS recovery of 17.43 MPa. The utilization of natural antioxidants markedly enhanced shear bond strength, with prolonged exposure durations resulting in increased bond strengths. Moringa oleifera (19.00 MPa at 20 minutes) surpassed Salvadora persica (17.51 MPa at 20 minutes). Failure mode analysis revealed heightened cohesive failures in the antioxidant-treated groups, refereed to the enhanced bond strength. Conclusion: Natural antioxidants promptly reestablish SBS post-bleaching, presenting a clinically feasible alternative to deferred bonding. Moringa oleifera exhibited enhanced effectiveness, indicating its promise for prompt restorative interventions following bleaching. Subsequent research ought to refine application techniques and investigate the long-term impacts on bond durability.

Introduction:

Tooth discoloration is a prevalent aesthetic challenge impacting individuals across all age groups, arising from several intrinsic and extrinsic factors. The development of esthetic dentistry has resulted in an increasing demand for different teeth-whitening methods, especially bleaching procedures conducted in clinical settings or at home [(1)]. Dental bleaching can be defined as a procedure employed to restore the original natural color of teeth or produce a whiter shade, and it is a common practice in dentistry [(2)]. These techniques predominantly utilize hydrogen peroxide and carbamide peroxide as the active compounds that decompose stains and enhance tooth brightness. Although its effectiveness, bleaching agents have been documented to cause detrimental effects on enamel structure, such as demineralization, decreased calcium and phosphate levels, and heightened enamel porosity, potentially undermining the longevity of subsequent restorative procedures [(3)].

A significant difficulty in restorative dentistry post-bleaching is the diminished binding strength between resin composites and bleached enamel. This behavior is ascribed to the residual oxygen radicals remaining from bleaching chemicals, which disrupt the polymerization process of adhesive materials that clearly reduces the shear bond strength [(4)]. In clinical practice, quick restoration may be essential when existing composite restorations fail to align with the freshly bleached tooth shade or when patients necessitate urgent restorative intervention. The diminished bond strength is a considerable issue, requiring the investigation of appropriate strategies to mitigate this negative impact [(5)].

Various strategies have been suggested for reestablishing the bond force strength of resin composites to bleached enamel, including the mechanical ablation of the superficial enamel layer, extending the bonding duration by postponing restoration for 24 hours to three weeks, applying adhesives that included organic solvents, and administering antioxidant agents such as catalase and sodium ascorbate. Nevertheless, the post-bleaching interval is frequently unfeasible, as numerous patients need immediate restoration for aesthetic and functional purposes. As a result, the introduction of antioxidants has garnered considerable interest as a viable method to quickly mitigate the residual effects of bleaching agents and improve resin bond strength [(6)].

Antioxidants are often categorized into two types: endogenous and exogenous. Endogenous refers to substances that can be synthesized by the human body, such as superoxide dismutase (SOD), catalase (CAT), and reduced glutathione (GSH). Exogenous refers to substances that the human body is incapable of synthesizing. Frequently utilized exogenous antioxidants include ascorbic acid (vitamin C), tocopherol (vitamin E), quercetin, tannic acid, and N-acetyl cysteine (NAC) [(7)].

In dental practice, antioxidant has many uses, they can be used in restoring shear bond strength of resin composite to bleached enamel by reducing the amount of residual free radicals and prevent mineral loss. In dental implant, antioxidant serve to minimize oxidative damage resulting from titanium corrosion and friction during placement, therefore improving osseointegration, lowering inflammation (including peri-implantitis), and promoting tissue regeneration. Antioxidants can be used to mitigate cytotoxic effects, DNA damage, and inflammation caused by materials such as mercury or unpolymerized monomers (e.g., HEMA, Bis-GMA) and enhance biocompatibility of restorative materials using amalgam, resin composite and glass ionomer cements. Additionally, antioxidants are employed in periodontal therapy to reduce tissue inflammation and oxidative stress linked to conditions such as periodontitis [(7)].

Natural extracted antioxidants have lately appeared as promising agents for mitigating the detrimental effects of bleaching on enamel. Moringa oleifera and Salvadora persica (Miswak)
have been recognized as promising bioactive substances with potential applications in dentistry providing potent antioxidant, anti-inflammatory and

antibacterial qualities. Research has shown their efficacy in enhancing oral health by suppressing inflammatory mediators, diminishing oxidative stress, and bolstering bone density, rendering it an appropriate choice for dental applications [8,9]. Moringa oleifera, commonly known as the "miracle tree," is a high in nutrients plant extensively grown in Asia, Africa, and South America. Well-known for its abundant vitamins, minerals, and antioxidants, every part of the plant comprising leaves, seeds, and flowers, it is utilized for nutritional and therapeutic applications. Research has validated its efficacy in addressing several health concerns owing to its antibacterial, antifungal, anti-inflammatory, antioxidant, and anti-malarial capabilities. The leaves are particularly efficient, demonstrating significant antioxidant activity due to their elevated phenolic and flavonoid concentrations [10]. Salvadora persica, sometimes referred to as the "toothbrush tree" or "miswak", has been utilized for ages as a natural medicine, particularly for preserving oral health and alleviating pain. It predominantly grows in the tropical and subtropical regions of Asia and Africa, where individuals have traditionally utilized its roots and stems for dental hygiene and to treat diseases such as coughs, asthma, headaches, and liver disorders. Studies indicate that this plant contains beneficial chemicals, including alkaloids (salvadorine, salvadoricine), flavonoids such as quercetin, triterpenes, phytosterols, and essential oils rich in benzyl isothiocyanate, all of which confer potent antioxidant and analgesic properties [8]. This study aims to conduct to assess the effect of varying application durations (10, 15, and 20 minutes) of two types of natural antioxidants ethanolic extracts (Moringa oleifera and Salvadora persica) on shear bond strength (SBS) of resin composite to bleached enamel surface.

Materials and Methods

Ethical approval was gained from the Research Ethical Committee at the Faculty of Dentistry, Mosul University, Iraq, with clearance number RCE reference number UoM.Dent. 24/1008.

Teeth Sample Preparation

One hundred eight sound premolars, extracted for orthodontic purposes from patients aged 16 to 20 years, were assessed to confirm the absence of cracks, cavities, or other enamel defects. They were subsequently cleaned with an ultrasonic scaler (Rundeer, China), then, stored and disinfected by immersion in 0.1% thymol solution for about two weeks [11]. The tooth crowns were transversely sectioned 2 mm below the cementoenamel junction utilizing a dual-sided diamond carbide disc (disc replaced for each 3 teeth) (Zhengzhou Smile, China) with a continuous water supply for effective cooling during the procedure, and each crown was subsequently incorporated in acrylic resin with the labial surface facing upwards. The central region of the labial surface was refined using a 600-grit silicon disc (disc replaced for each 3 teeth) (Zhengzhou Smile, China) attached to a handpiece mounted on a locally modified, horizontally positioned microscope base to ensure optimal standardization as shown in figure (1), thereby creating a smooth, flat enamel surface for all tooth specimens as shown in figure (2). The flat enamel surface of each specimen has been examined by using a stereomicroscope at 30x magnification to confirm the absence of defects, cracks, or visible dentin [12].

Sample grouping

A total of 108 tooth specimens will be randomly allocated into nine groups according to surface treatment and bonding duration (n = 12):

Group 1: Unbleached enamel (intact enamel without treatment) (positive control).

Group 2: Bleaching only (negative control).

Group 3: Bleaching with a subsequent one-week delay prior to bonding.

Group 4: Bleaching followed by a 10-min. treatment with 80% Moringa oleifera extract.

Group 5: Bleaching followed by a 15-min. treatment with 80% Moringa oleifera extract.

Group 6: Bleaching followed by a 20-min. treatment with 80% Moringa oleifera extract.

Group 7: Bleaching followed by a 10-min. treatment with 80% Salvadora persica extract.
Group 8: Bleaching followed by a 15-min. treatment with 80% Salvadora persica extract.
Group 9: Bleaching followed by a 20-min. treatment with 80% Salvadora persica extract.
All groups will undergo testing 24 hours post-bonding, except for Group 3, which will be examined after one week.

Antioxidant preparation

Leaves of Moringa Oleifera (MO) were collected from a local farm in Erbil City, Iraq, while the roots of S. persica (Salvadoraceae), referred to as Arak, were imported from Jeddah, Saudi Arabia. Both specimens were identified and extracted in the Department of Biochemistry, College of Education, University of Mosul, Iraq.

The extraction of both plant materials (root of Salvadora Persica and leaves of Moringa Oleifera) involved washing the fresh leaves and roots with distilled water, shade-drying them at ambient temperature (22–25 °C), and grinding them into a powder using an electric grinder (Silver Crest, Germany). The powder (200 g) was first defatted with 2000 ml of petroleum ether (boiling range 60-80°C) (Scharlab S.L., Spain) and stirred for 24 hours using a locally produced adapted mechanical stirrer. The mixture was subsequently filtered by Whatman filter paper size No. 1 (Double Rings, China) and permitted to dry at ambient temperature [13]. The desiccated powder was submerged in 2000 cc of 70% ethanol and stirred mechanically for 72 hours at ambient temperature (22-25°C) in total darkness. The extract will thereafter undergo two filtration processes using Whatman filter paper size No. 1 (Double Rings, China). The solvent will be completely removed using a rotary evaporator (GWSI, Zhengzhou, China). The extract was obtained and stored in tubes at 4°C until used [14, 10].

Preparation of artificial saliva

The artificial saliva was formulated according to the subsequent recipe: 4.3 g xylitol, 0.1 g potassium chloride, 40 mg potassium phosphate, 1 g sodium carboxymethylcellulose, 0.1 g sodium chloride, 5 mg calcium chloride, 5 mg magnesium chloride, 0.02 mg sodium fluoride, 1 mg potassium thiocyanate, and 100 g distilled deionized water, resulting in a pH of 7 at temperature 37 °C [15].

Bleaching procedure

The Power Whitening YF 40% HP, paired with an auto mixing tip, will have a 1 mm layer of bleaching gel applied to the enamel surface for 20 minutes over three consecutive cycles, in compliance with the manufacturer's instructions. Following each cycle, the teeth will be meticulously rinsed with water for 60 seconds and subsequently air-dried for 30 seconds [16]. subsequent to the bleaching technique, samples from all groups will be held in artificial saliva for 24 hours prior to testing, except for group (2), which will be preserved in artificial saliva for one week until testing purposes. Throughout the experiment's duration, the teeth were preserved in artificial saliva at temperature of 37°C to replicate oral circumstances. The artificial saliva was made and replaced daily, and a digital pH meter (Juanjuan, China) was utilized to measure the solution's pH [15].

Application of antioxidants and bonding procedure

Subsequent to the bleaching treatment, the flat enamel labial surface will be addressed with a light-cured resin barrier [17]. Subsequently, a syringe will be employed to deliver 1 ml of each antioxidant according to their designated group for the specified duration. The surfaces will then be cleansed in distilled water for thirty seconds and dried for five seconds using compressed air. [18].

Enamel surface will be treated with acid etch consist of 37% phosphoric acid (Meta Etchant, Meta Biomed, Korea) for 30 seconds; subsequently it will be flushed with distilled water for 15 seconds and dried using air for 10 seconds [19]. The universal adhesive was (Ivoclar, Liechtenstein) meticulously applied to the flat labial enamel surface, then followed by a gentle air jet for 10 seconds, in line with the manufacturer's specifications. Before light curing, a composite tube was made from a 2 mm diameter plastic mold with a height of 2 mm over an adhesive-coated enamel surface [(20)]. The adhesive was polymerized using light for 20 seconds with a curing pen [(16)]. The A1 hue of IPS Empress Direct (Enamel shade) (Ivoclar, Liechtenstein) will be utilized in a PVC mold and subsequently compressed with a glass slide over the composite material. The material will initially be cured from the top for 20 seconds, followed by light curing from four directions for an additional 20 seconds after the removal of the glass slide, employing a curing device with an intensity of 1200 mw/cm² (eightteeth, china) [(21)].

A plastic tube was carefully incised vertically with a sharp lancet, producing a composite tube bonded to the enamel. Specimens were thereafter stored in artificial saliva for 24 hours, except for group (2), which was maintained in artificial saliva for one week before to testing [(15)].

Shear bond strength test

The SBS was conducted using a universal testing machine at a cross-head speed of 0.5 mm/min, with a 0.2 mm stainless steel wire loop to exert force on the tooth specimen at the enamel-composite interface until debonding resulted [(12)] as shown in figure (3).

A custom locally produced metal holder mold was designed with an interior diameter that corresponds to that of the specimen mold, ensuring consistent alignment of the experimental tooth sample bases when secured in the universal testing apparatus as shown in figure (4). The Shear Bond Strength Test (SBS) was calculated using the measured diameter of the specimen according to the following equation: $\sigma = F/A$, where σ refers to shear bond strength quantified in Mega Pascals (MPa). F refers to the failure load quantified in Newtons (N). A refers to the surface area in square millimeters (mm²) [(12)].

Failure mode analysis utilizing a stereomicroscope:

Subsequent to the shear bond strength test, the surfaces of the tooth samples were examined under a stereomicroscope at 30x magnification to determine the characteristics of the failure at the bonding interface between the enamel and composite resin in each specimen. The failures were classified into 3 groups [(22)]:

Adhesive: Failure of adhesion at the interface between the bonding agent and the enamel.

Cohesive: Failure within the composite resin material.

Mixed: A combination of adhesive and cohesive failure.

A single representative specimen image utilized from each group using SEM device, the specimen was air-dried and adhered to the aluminum stub using carbon-coated double-sided adhesive tape. The specimen was subsequently coated with gold using sputter coating and evaluated by a single individual at magnifications of 70X.

Statistical analysis

The findings were statistically analyzed using SPSS software version 20.0 (IBM, SPSS Statistics for Windows, Armonk, NY, USA). Following the Shapiro-Wilk test for normality at a significance level of 0.05, the data were statistically analyzed using parametric two-way ANOVA and the Duncan Multiple Range Test at $P \leq 0.05$ significance level.

Results

Shear bond strength

The descriptive statistics of shear bond strength for all tested groups are shown in Table (1) and Figure (5).

The result indicated the highest mean of shear bond strength was observed with Unbleached enamel group (26.2208± 0.22101), and the lowest was with the Bleached enamel group (6.3900± 0.27872).

The Moringa Olivera and Salvadora persica application groups were observed to have greater shear bond strength compared to bleached enamel group, the shear bond strength value increased as the application time increased. The shear bond strength groups data were verified to be normally distributed using Shapiro-wilk test. Two-way ANOVA test for the effect of antioxidant types, application times and their interaction levels on shear bond strength shown in Table (2), were revealed a significant difference among all the tested groups ($P \leq 0.05$) for all levels of factors. The Duncan's multiple range test for the shear bond strength groups shown in Table (3) revealed that the unmodified enamel group exhibited significantly higher shear bond strength (26.2208 ±0.221) than other groups. The bleached enamel group exhibited significantly lower shear bond strength (6.3900±0.278) than any other group. The (B+MO 20 min.) provided the higher shear bond strength (19.0019±0.171) among Moringa Oleifera antioxidant groups and transcended the delayed group. The (B+SP 20 min.) group provided the higher shear bond strength (17.5159±0.132) among Salvadora persica antioxidant groups and was comparable to that of the delayed group.

Mode of failure

After the bond strength tests, the surfaces of the Samples have been evaluated using a stereomicroscope at 70x magnification to determine the type of failure that occurred concerning the relation of enamel and composite resin for each specimen, as shown in Table (4) and represented in Figures (6, 7, and 8). Adhesive failure (adhesive dislocation at the resin/tooth interface) was shown to occur in 100% of Bleached enamel, B+MO 10 min., and B+SP 10 min. groups, while it occurred in 91.6% of the B+SP 15 min. group.

The cohesive failure occurred mostly (33.3%) in the B+MO 20 min**.** group, followed by the unmodified enamel (non-bleached) group (25%), and it was 16.7% in the Delayed Bonding, B+MO 15 min., and B+SP 20 min. groups.

The mixed failure occurred mostly (25%) in the delayed bonding group, followed by the unmodified enamel and B+MO 15 groups (16.7%), while it was 8.3% in the B+MO 20 min**.**, B+SP 15 min., and B+SP 20 min. groups.

Discussion

The quest for dental aesthetics has resulted in a heightened desire for conservative whitening methods, with bleaching becoming as one of the most prevalent approaches to improve smile look. The procedure entails the decomposition of organic chromogens in the enamel and dentin, yielding lighter-hued molecules and an enhanced tooth brightness [(23)]. In-office bleaching treatments, especially those employing high-concentration hydrogen peroxide (15%–38%), have shown considerable effectiveness in producing quick and observable whitening results [(24)]. Nonetheless, despite these advantages, apprehensions have emerged regarding the influence of bleaching chemicals on the structural properties of enamel, particularly their effect on the bond strength of resin-based restorations.

Prior research indicates that bleaching modifies the surface properties of enamel, resulting in lowering shear bond strength (SBS) of resin composite material to enamel [(3)]. The principal factor contributing to this reduction is the residual oxygen layer produced by bleaching chemicals, which obstructs resin entry into the etched enamel and hinders polymerization [(4)]. Moreover, bleaching has been demonstrated to diminish enamel minerals, including calcium and phosphate, thereby further compromising the bonding contact. Scanning electron microscopy (SEM) assessments indicate that resin tags in bleached enamel are diminished in quantity, reduced in length, and less distinct than those in unbleached enamel, leading to worse adhesion and heightened likelihood of restoration failure [(3)]. Furthermore, alterations in enamel morphology, such as greater porosity, increased surface roughness, and diminished microhardness, have been documented subsequent to bleaching, hence affecting bond strength [(25)]. Various solutions have been investigated to mitigate the detrimental effects of bleaching on bonding. Antioxidants have garnered significant attention as natural bioactive compounds for dental applications [(26, 27)]. These bioactive compounds demonstrate potent free radical scavenging capabilities [28]. The leaves of Moringa oleifera are characterized by elevated concentrations of quercetin, kaempferol, and gallic acid, which collectively enhance their significant antioxidant properties [29]. Salvadora persica, or miswak, contains bioactive substances like tannins, alkaloids, and benzyl isothiocyanate, which have demonstrated efficacy in promoting dental health and enhancing enamel remineralization [26]. This study is designed to assess the impact of Moringa oleifera and Salvadora persica ethanolic extract on SBS post-bleaching, that focuses on the ideal timing through the three suggested distinct application durations (10, 15, and 20 minutes) to restore the shear bond strength without requiring extended post-bleaching intervals, in light of the growing interest in natural alternatives to synthetic one.

This study's findings demonstrate that bleaching significantly diminishes the shear bond strength (SBS) of composite resin to enamel. The bleached enamel group exhibited the lowest SBS value (6.39 MPa) in contrast to the non-bleached enamel group (26.22 MPa), Table (3) illustrating the detrimental impact of bleaching on enamel adherence. This outcome corresponds with prior research indicating that remaining oxygen molecules emitted during bleaching disrupt resin polymerization, resulting in diminished bond strength [20]. Reports indicate that even at lower concentrations of bleaching chemicals, such as 3% and 10% carbamide peroxide, bond strength is markedly diminished in comparison to unbleached enamel [30]. The current investigation employed a high concentration of hydrogen peroxide (40%), which likely led to an increased accumulation of free radicals, intensifying the reduction in bond strength [17]. On other side, there are several studies that explain there is no substantial dissimilarity in shear bond strength after and before bleaching procedure of enamel surfaces. [31, 32]. In addition to residual free radicals there are multiple factors that contribute to the diminished bond strength immediately following bleaching, previous research has shown that the diminution in bond strength is attributable to the demineralization of dental tissues, the decrease in dental tissue surface energy, and the denaturation of dentinal collagen subsequent to bleaching. The structural alterations are directly related to the concentration and duration of application of the whitening agent [18]. The loss of enamel minerals is also significantly reduces bond strength; a prior study indicated that the depletion of calcium, diminished microhardness, change of organic components, loss of prismatic structure, and increased enamel porosity are detrimental effects observed following carbamide peroxide bleaching [33]. A supplementary approach to reestablish bond strength involves postponing the bonding process subsequent to bleaching. The findings of this study demonstrate that a one-week postponement resulted in a notable enhancement in SBS, with the delayed bonding group achieving a mean value of 17.43 Mpa in comparative with immediate bonding of bleached enamel group (6.39 MPa) Table (1). This corroborates with studies indicating that a waiting interval facilitates the dissipation of residual oxygen, hence diminishing its inhibitory impact on composite polymerization [34]. Nevertheless, despite this enhancement, the SBS did not quite revert to the levels seen in the non-bleached control group, indicating that an extended waiting period may be required for full restoration. Additional research has demonstrated that a two-week interval is more efficacious in reestablishing bond strength to pre-bleaching levels [35]. Although postponing bonding is a feasible approach, it may lack practicality in clinical scenarios necessitating quick restoration.The utilization of natural antioxidants, Moringa oleifera and Salvadora persica, markedly enhanced SBS in this research. The findings indicate that both antioxidants significantly improved bond strength relative to the bleached enamel group, as extended treatment durations producing superior outcomes. Moringa oleifera exhibited enhanced performance, with SBS rising from 12.48 MPa at 10 minutes to 19.00 MPa at 20 minutes, that value exceed that of delay bonding group but less than that of unbleached group.

Salvadora persica also enhanced bond strength, but to a lesser degree, achieving 17.51 MPa at 20 minutes that is comparable to that of delay bonding group. These findings correspond with prior research demonstrating a direct correlation between the timing of antioxidant application and the recovery of bond strength [22, 33, 36]. From other hand, another study explains that there are no differences of antioxidant activity that applied at two different application time (10 min., 20 min.) [37].

The superior efficacy of Moringa oleifera is ascribed to its elevated levels of phenolic and flavonoid compounds, which are essential in counteracting free radicals and rejuvenating the bonding capacity of enamel [29]. These substances, such as quercetin and kaempferol, efficiently scavenge oxygen radicals, hence promoting the polymerization of adhesive resins [38].

The relatively diminished efficacy of Salvadora persica may result from its reduced polyphenol concentration and variations in its antioxidant mechanism. Although Salvadora persica possesses bioactive components such tannins and alkaloids, its radical scavenging capacity is inferior to that of Moringa oleifera [39]. This indicates that either an extended treatment duration or an increased concentration may be required for Salvadora persica to attain similar SBS repair [40]. Nonetheless, the findings suggest that both antioxidants offer a physiologically acceptable alternative to delayed bonding by markedly enhancing shear bond strength following bleaching.

The mode of failure analysis further confirms the results of this study. According to Table (4), with the extension of application duration, cohesive failures occurred more frequently, especially in the Moringa 20-minute group and the unbleached control group. Mixed failures were noted in the delayed bonding group and in some Moringa and Salvadora groups, suggesting intermediate bonding strength. These findings align with other research indicating a reduction in adhesive failures and an elevation in cohesive failures following extended antioxidant application [41]. Also, our findings correspond with another study indicating that the increased adhesive failure mode in the bleached group is attributed to the diminished bonding between bleached enamel and resin composite [19].

The mode of failure investigation indicates that Moringa oleifera is superior in restoring bond strength relative to Salvadora persica, since the largest occurrence of cohesive failure was noted in the Moringa 20 min group.

This study possesses certain limitations that must be acknowledged when analyzing the results. The study was performed in a controlled laboratory environment, which may not accurately reflect intraoral circumstances, including variations in temperature, salivary flow, and mechanical forces from mastication considering the bond's long-term stability, varying bleaching concentrations or other materials like carbamide peroxide comparing the results with other types of antioxidant materials with other application techniques.

Conclusion

With regard to the limitations of the current study, this study demonstrates that bleaching markedly decrease the shear bonding strength (SBS) of composite resin to enamel, with the bleached enamel group exhibiting the lowest SBS values. Delaying bonding for 7 days partially reestablished SBS, however it did not attain the levels reported in the unbleached enamel group. The utilization of natural antioxidants, Moringa oleifera and Salvadora persica, significantly improved SBS post-bleaching, and their effects increased with extended treatment durations producing superior outcomes. Moringa oleifera exhibited exceptional efficacy, attaining the maximum SBS recovery at 20 minutes post-application, positioning it as a viable option to delayed bonding.

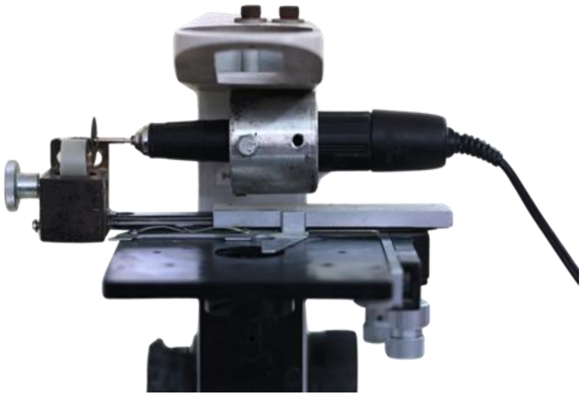


Figure (1): flattened labial surface using locally modified microscope

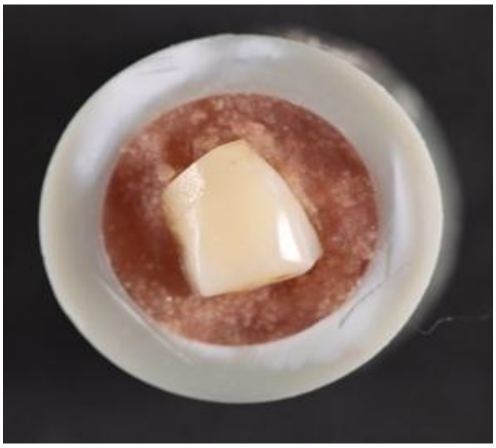
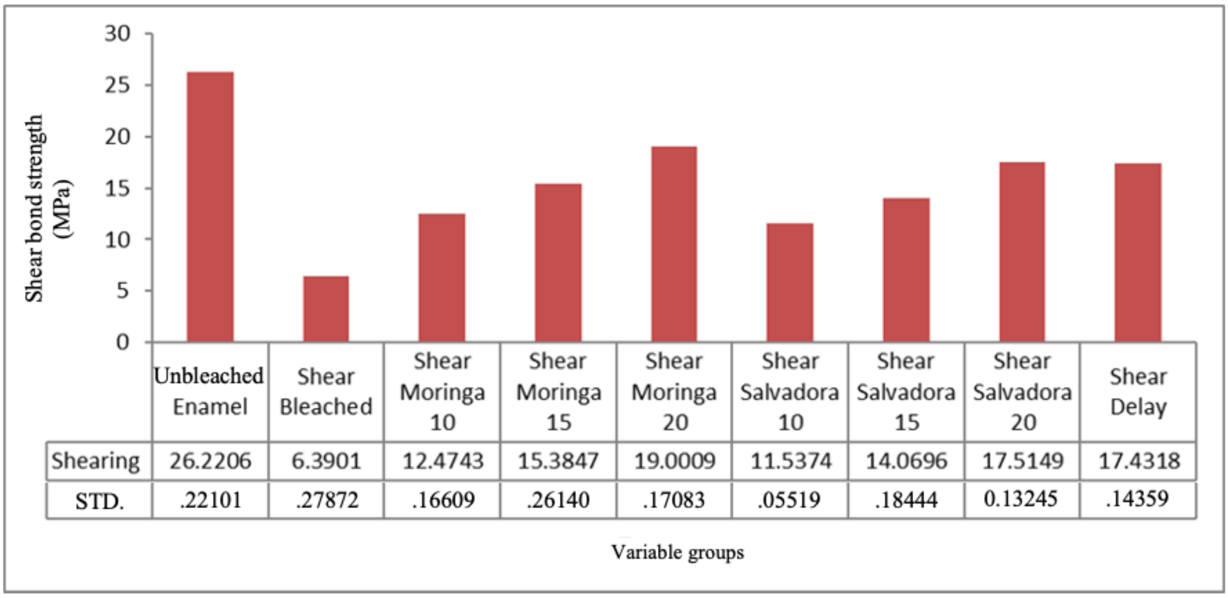


Figure (2): The tooth crown sample with flat labial surface.

Figure (3): universal testing machined device for shear bond strength test.

Figure (4): Locally made metal holder used for universal testing machined device for shear bond strength test.



	Unbleached Enamel	Shear Bleached	Shear Moringa 10	Shear Moringa 15	Shear Moringa 20	Shear Salvadora 10	Shear Salvadora 15	Shear Salvadora 20	Shear Delay
Shearing	26.2206	6.3901	12.4743	15.3847	19.0009	11.5374	14.0696	17.5149	17.4318
STD.	.22101	.27872	.16609	.26140	.17083	.05519	.18444	0.13245	.14359

Figure (5): Bar chart of means of shear bond strength of all test groups.

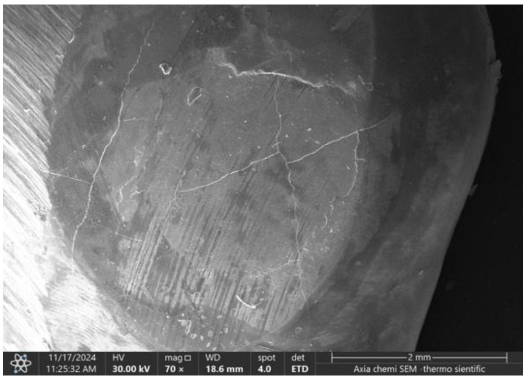


Figure 6: The representative SEM image at 70X magnification shows an adhesive fracture.

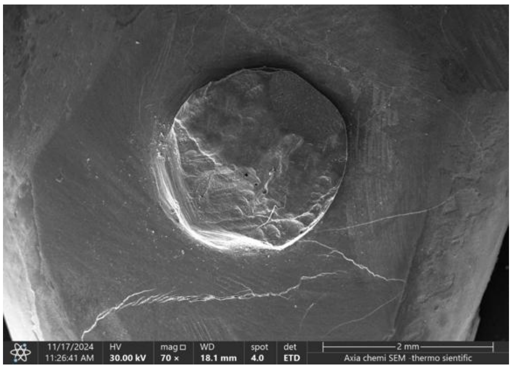


Figure 7: The representative SEM image at 70X magnification shows a cohesive fracture.

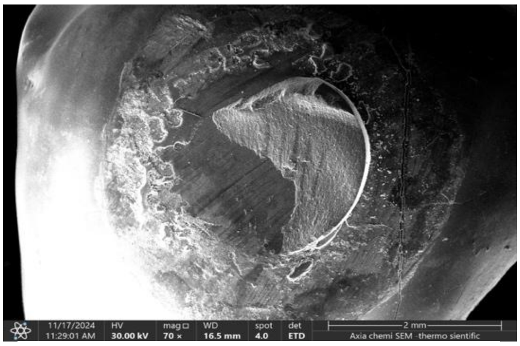


Figure 8: The representative SEM image at 70X magnification shows a mixed fracture.

Table 1: Descriptive statistics of shear bond strength for all tested groups.

Variables	N	Min.	Max.	Mean(N)	Std. Deviation
Unbleached Enamel	12	25.87	26.58	26.2208	.22101
Bleached only	12	6.01	6.75	6.3900	.27872
B+MO 10 min.	12	12.22	12.73	12.4750	.16609
B+MO 15 min.	12	15.00	15.68	15.3854	.26140
B+MO 20 min.	12	18.79	19.22	19.0019	.17083
B+SP 10 min.	12	11.46	11.61	11.5379	.05519
B+SP 15 min.	12	13.81	14.33	14.0701	.18444
B+SP 20 min.	12	17.30	17.73	17.5149	.13245
B+ Delayed	12	17.20	17.67	17.4318	.14359

B: bleaching, MO: Moringa Oleifera, SP: Salvadora Persica, (N) : Newton.

Table 2: Two-way ANOVA test for antioxidant types, application times and their interaction on the shear bond strength.

Source of variance	Type III Sum of Squares	df	Mean Square	F	Sig.
Antioxidant types	20.963	1	20.963	500.538	*.000
Application times	1805.401	3	601.800	1.437E4	*.000
Antioxidant types * Application times	7.935	3	2.645	63.153	*.000
Error	3.685	88	.042		
Total	17679.308	96			
Corrected Total	1837.984	95			

* statistically significant at $p \leq 0.05$. df: degree of freedom.

Table 3: Duncan's multiple range test for shear bond strength groups.

Groups	N	Mean ± SD	Duncan groups**
Unbleached Enamel	12	26.2208 ±0.221	A
Bleached only	12	6.3900±0.278	H
B+MO 10 min.	12	12.4750±0.167	F
B+MO 15 min.	12	15.3854±0.261	D
B+MO 20 min.	12	19.0019±0.171	B
B+SP 10 min.	12	11.5379±0.055	G
B+SP 15 min.	12	14.0701±0.184	E
B+SP 20 min.	12	17.5159±0.132	C
B+ Delayed	12	17.4323±0.144	C

B: bleaching, MO: Moringa Oleifera, SP: Salvadora Persica. **Different letters mean highly significant different at $p \leq 0.05$.

Table 4: Mode of failure for the test groups.

Variables groups	Adhesive failure	Cohesive failure	Mixed failure
Unbleached enamel	7(58.3%)	3(25%)	2(16.7%)
Bleached only	12(100%)	0(0%)	0
B+MO 10 min.	12(100%)	0(0%)	0
B+MO 15 min.	8(66.6%)	2(16.7%)	2(16.7%)
B+MO 20 min.	7(58.3%)	4(33.3%)	1(8.3%)
B+SP 10 min.	12(100%)	0	0
B+SP 15 min.	11(91.6%)	0	1(8.3%)
B+SP 20 min.	9(75.0%)	2(16.7%)	1(8.3%)
B+ Delayed	7(58.3)	2(16.7%)	3(25%)

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