

Effect of Flavonoids on Resin Bond Strength Following Tooth Bleaching: A Systematic Review

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Abstract

Objective: To evaluate whether application of natural flavonoid-based antioxidants following tooth bleaching would enhance the immediate bond strength of dental adhesives to bleached enamel, through a systematic review of in vitro and in vivo studies.

Materials and methods: A systematic literature search was performed in five electronic databases (Cochrane (CENTRAL), MEDLINE, Scopus, Science Direct and Web of Science) up to from June 2005 to June 2025, available in English language. Studies were selected according to PICOS criteria. Methodological quality was assessed using the Joanna Briggs Institute (JBI) criteria for analytical cross-sectional studies.

Results: A total of 41 studies met the eligibility criteria and were included in the qualitative analysis. The included studies were evaluated a wide range of flavonoids and related plant-derived antioxidants, including grape seed extract (proanthocyanidin), green tea extract (epigallocatechin gallate), quercetin, naringin, cranberry extract, propolis, guava seed extract, strawberry extract, aloe vera, pine bark extract, rosemary extract, and others. Grape seed extract/proanthocyanidin and epigallocatechin gallate (EGCG) showed the most consistent evidence of bond strength restoration to control levels.

Conclusion: The available evidence suggests that the application of flavonoid antioxidants, particularly grape seed extract/proanthocyanidin and EGCG, can restore or significantly improve resin bond strength to bleached enamel, supporting their use to facilitate immediate restorative procedures after bleaching. However, as most evidence is derived from in vitro studies, clinical trials are warranted to confirm these findings.

Keywords: epigallocatechin gallate, flavonoids, grape seed extract, resin bond strength, quercetin

INTRODUCTION

Dental bleaching is one of the most widely sought esthetic dental treatments, reflecting the growing patient demand for whiter, more attractive smiles.¹ Vital tooth bleaching using peroxide-based agents — both in-office (high-concentration hydrogen peroxide, 30–40%) and at-home (low-concentration carbamide peroxide, 10–21%) is well established as a conservative, safe, and effective approach to managing tooth discoloration.^{2,3} The mechanism of bleaching involves the release of free radical oxygen species that degrade chromogenic pigment molecules within the tooth structure into smaller, less colored compounds.⁴ However, this process also produces residual free radicals that penetrate the enamel and dentinal tubules, where they interfere with the penetration and polymerization of resin monomers.^{5,6} The result is a significant, transient reduction in the bond strength of adhesive restorations applied immediately after bleaching.⁷ This phenomenon has been well documented, and a waiting period of at least one to three weeks has traditionally been recommended before adhesive procedures are undertaken.^{8,9}

Such a mandatory waiting period poses a significant clinical inconvenience. Patients frequently require restorative treatment immediately after bleaching whether for carious lesions, anterior restorations, bracket cementation, or other adhesive procedures and the delay can compromise patient compliance and treatment efficiency.¹⁰ Consequently, considerable interest has emerged in identifying antioxidant agents capable of neutralizing residual peroxide radicals and thereby permitting immediate adhesive procedures after bleaching.¹¹

Sodium ascorbate, a synthetic derivative of vitamin C, has been the most extensively studied antioxidant for this purpose and has traditionally been regarded as the gold standard for reversal of post-bleaching bond strength reduction.¹² However, concerns regarding mutagenic potential for mammalian somatic cells and a short shelf life have prompted investigation of natural alternatives.^{13,14} Among these, flavonoids a large class of plant-derived polyphenolic compounds have attracted particular attention due to their potent antioxidant and free radical scavenging properties, biocompatibility, and relative ease of preparation.¹⁵

Flavonoids encompass a diverse range of compounds, including flavanols (e.g catechins present in green tea and grape seed extract), flavonols (e.g quercetin), flavanones (e.g naringin), and anthocyanins (e.g cranberry and strawberry extracts).¹⁶ These compounds exert their antioxidant effects through multiple mechanisms: hydrogen atom donation, electron transfer, metal chelation, and inhibition of oxidative enzymes.¹⁷ Grape seed extract, rich in oligomeric proanthocyanidins (OPCs), has been reported to possess antioxidant activity significantly greater than that of vitamins C and E.^{18,19} Similarly, epigallocatechin gallate (EGCG), the predominant catechin in green tea, has demonstrated strong free radical quenching activity.²⁰ Other flavonoids, including quercetin, naringin, guava seed extract, and cranberry extract, have been investigated in more recent studies. Despite a growing body of individual in vitro studies, no comprehensive systematic review has yet aggregated the evidence specifically on flavonoid antioxidants in the context of post-bleaching bond strength recovery. The present systematic review was therefore undertaken to critically evaluate the available evidence on whether the application of flavonoid antioxidants following tooth bleaching can restore or enhance the immediate bond strength of dental adhesives to bleached enamel. The hypothesis tested was that flavonoid antioxidants, when applied to bleached enamel prior to adhesive procedures, can significantly improve resin bond strength.

MATERIALS AND METHODS**Literature Search:**

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.²¹ The PROSPERO registration no is CCRD420251022366. The electronic literature search was performed independently by two reviewers (S.B and K.R), covering publications from June 2005 to June 2025. The following databases were searched: (Cochrane (CENTRAL), MEDLINE, Scopus, Science Direct and Web of Science). The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords, including: ("flavonoids" OR "plant extracts" OR "grape seed extract" OR "green tea" OR "epigallocatechin gallate" OR "quercetin" OR "proanthocyanidin" OR "herbal antioxidants" OR "natural antioxidants") AND ("tooth bleaching" OR "dental bleaching" OR "hydrogen peroxide" OR "carbamide peroxide") AND ("bond strength" OR "shear bond strength" OR "tensile bond strength" OR "dental adhesion") AND ("dental enamel" OR "enamel" OR "dentin" OR "resin composite"). All retrieved records were imported into reference management software to facilitate duplicate removal.

Study Eligibility

Studies were selected using the following PICOS framework:

Population (P): Human or bovine teeth bleached with peroxide-based agents.

Intervention (I): Application of flavonoid or other natural antioxidants following bleaching, with immediate adhesive restoration.

Comparison (C): Teeth without antioxidant intervention (bleached without antioxidant, or non-bleached control), or teeth treated with non-flavonoid antioxidants (sodium ascorbate).

Outcome (O): Bond strength (shear bond strength, micro-shear bond strength, microtensile bond strength, push-out bond strength) at the resin-tooth interface.

Study Design (S): In vitro studies, in vivo studies, randomized controlled trials, non-randomized controlled trials, case series, and before-and-after study designs.

Inclusion criteria were: (1) studies evaluating the effect of natural flavonoids or plant-derived antioxidants on bond strength of adhesive systems to bleached enamel or dentin; (2) studies including a control group (non-bleached and/or bleached without antioxidant); and (3) reporting bond strength data as the primary outcome. Exclusion criteria were: (1) review articles and survey reports; (2) studies using only synthetic antioxidants without a natural antioxidant arm; (3) animal studies (other than in vitro use of bovine teeth); and (4) studies not reporting bond strength as an outcome.

Study Selection

Titles and abstracts were screened independently by two reviewers (S.B and K.R) following duplicate removal. Full-text articles were obtained for all studies considered potentially eligible. Any disagreement between reviewers at any stage was resolved through discussion and consensus with third author (I.U). The PRISMA flow chart illustrating the study selection process is presented as Figure 1.

Data Extraction

Relevant data were extracted by two independent reviewers using a standardized data extraction form. Extracted information included: study reference and country, aim of the study, sample size and sample type, type of bleaching (intra-coronal or extra-coronal), bleaching agent and product used, type of flavonoid antioxidant used and its concentration, comparative groups, duration of antioxidant application, bonding agent and restorative material used, bond test technique employed, storage conditions before and after bleaching, antioxidant application, and restoration, primary and secondary outcomes, and conclusions. Missing data were managed by recording "not mentioned" in the extraction form.

Quality Assessment

The methodological quality of each included study was evaluated independently by two reviewers and discussion with a third author (I.U) using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for analytical cross-sectional studies.²² The JBI checklist assesses the following nine criteria: (1) appropriateness of the sample framework for the targeted population; (2) appropriateness of the recruitment process; (3) adequacy of sample size; (4) clarity of description of study setting and subject characteristics; (5) sufficiency of data analysis regarding sample identification; (6) use of appropriate procedures to verify the study condition; (7) reliability and appropriateness of condition assessment for each participant; (8) adequacy of the response rate and management of non-response; and (9) appropriateness and fit of the statistical analysis. Each criterion was scored as "Yes," "No," or "NA" (not applicable). Studies that could not be fully evaluated due to insufficient data were assessed separately and noted accordingly.

RESULTS

Search Strategy

The database search retrieved a total of 384 records across all databases. After removing 96 duplicates, 288 records remained for title and abstract screening. Following this screening, 221 records were excluded as they did not meet the eligibility criteria based on their titles or abstracts. A total of 67 full-text articles were assessed for eligibility. After full-text review, 26 articles were excluded (3 studies did not evaluate natural antioxidants as the intervention, 14 studies did not report bond strength as an outcome, 5 were review articles, and 4 did not include a control group). Consequently, 41 studies were included in the qualitative synthesis.

Study Characteristics

The 41 included studies were published between 2011 and 2025, originating predominantly from India (n = 20), followed by Brazil (n = 7), Iran (n = 5), China (n = 4), Turkey (n = 2), Egypt (n = 1), and Indonesia (n = 1). One study was from Saudi Arabia and one from Brazil conducted with international collaboration. All included studies were in vitro studies, with the exception of one study that evaluated bond strength over a 3-year clinical follow-up period.¹⁴ Sample sizes ranged from 36 to 360 specimens. The detailed characteristics of all included studies are presented in Table 1.

Bleaching was predominantly performed using extra-coronal protocols (n = 35), while six studies employed intra-coronal bleaching techniques. High-concentration hydrogen peroxide ranging from 30% to 40% was the most frequently used bleaching agent, utilized in the majority of in-office simulations. Carbamide peroxide (10–21%) was used in at-home simulations. A wide variety of flavonoid and plant-derived antioxidants were evaluated across the included studies, including: grape seed extract or proanthocyanidin (OPCs) (n = 17 studies),^{19,20,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37} green tea extract or EGCG (n = 16 studies),^{3,9,11,16,17,32,36,37,38,39,40,41} quercetin (n = 3 studies),^{10,13,15} cranberry extract (n = 3 studies),^{1,8,19} aloe vera (n = 5 studies),^{14,28,33,34,38} pine bark extract (n = 5 studies),^{5,17,20,27,30} propolis (n = 2 studies),^{4,21} naringin (n = 1 study),⁷ guava seed extract (n = 1 study),³⁵ strawberry extract (n = 1 study),¹⁸ rosemary extract (n = 2 studies),^{11,30} curcumin (n = 1 study),² pomegranate peel extract (n = 2 studies),^{20,37} and others including sage, amla, pedicularis extract, white tea, and winter's bark. Most studies also included a sodium ascorbate experimental group as a positive comparator.

Bond strength was assessed using shear bond strength (SBS) testing in the majority of studies, with some employing micro-shear bond strength (μ SBS), microtensile bond strength (μ TBS), or push-out bond strength testing. Universal testing machines were used in all but a few studies. The application duration of antioxidants varied considerably across studies, ranging from 30 seconds to 120 minutes, with 10 minutes being the most commonly employed duration. Full methodological details and conclusions are provided in Table 2.

Narrative Synthesis of Results

Grape Seed Extract and Proanthocyanidins. Grape seed extract, applied in concentrations of 3% to 10% for durations of 1 to 10 minutes, was the most frequently evaluated flavonoid antioxidant across the included studies.^{18,19,23,24,25,28,29,30,31,32,37,38,39,40} The majority of studies reported that grape seed extract significantly improved or fully restored shear bond strength of composite resin to bleached enamel to levels comparable with non-bleached controls.^{18,19,23,24,25} Vidhya et al reported that 5% grape seed extract (OPC) applied for 10 minutes completely neutralized the deleterious effects of bleaching and significantly increased bond strength.²³ Xu et al demonstrated that GSE at a concentration $\geq 5\%$ could restore SBS compromised after bleaching within 1 minute of application.²⁴ Nair et al found that 6.5% grape seed extract was superior to both 10% sodium ascorbate and 50% aloe vera in restoring bond strength to baseline values.²⁸ Abraham et al confirmed the superiority of grape seed extract over sodium ascorbate, with 5th generation bonding agents demonstrating higher SBS.³⁸ However, not all studies reported complete restoration; Subramonian et al observed that 10% pine bark and grape seed extracts improved but did not fully restore bond strength to non-bleached enamel levels.²⁷

Green Tea Extract (Epigallocatechin Gallate, EGCG). Green tea was the second most frequently evaluated antioxidant, assessed in 16 studies using concentrations of 5% to 10% and application times of 10 to 60 minutes.^{3,9,11,16,17,32,36,37,38,39,40,41} Berger et al demonstrated that green tea restored microtensile bond strength of composite resin to bleached enamel to non-bleached control levels.³ Ozelin et al found that bond strength values were higher than bleached controls only when green tea antioxidants were applied for 60 minutes, highlighting the importance of application duration.¹⁶ Gündođdu et al reported that green tea alone, but not in combination with rosemary, exhibited bonding strength statistically similar to delayed restoration groups.¹¹ Sharafeddin et al noted that green tea had no significant effect on SBS of enamel bleached with 15% carbamide peroxide, but significantly increased SBS of enamel bleached with 38% hydrogen peroxide, suggesting a dependency on bleaching

agent concentration.³⁶ EGCG applied in a purer form (10–20% solution) demonstrated the ability to rescue resin-enamel bond strength after bleaching, as reported by Zhang et al.²⁵ Khamverdi et al showed that EGCG at 600–1000 μmol concentrations with application times of 10–20 minutes restored bond strength comparable to delayed bonding.⁴¹

Quercetin. Three studies evaluated quercetin as an antioxidant after bleaching.^{10,13,15} The full text of the study by Fattah et al. was not accessible; therefore, the required data were extracted from the abstract. Lin et al reported that quercetin pretreatment for 2 minutes prior to the bonding procedure preserved the immediate bond strength and improved aged bond strength of bleached dentin.¹³ Moradian et al found that 10% quercetin applied for 10 minutes increased bond strength to bleached enamel, but was not able to fully reverse it to unbleached control values.¹⁵ Fattah et al evaluated quercetin after internal bleaching and reported no significant difference compared to tannic acid control.¹⁰

Naringin. Carvalho et al conducted the most recent study in this systematic review, evaluating 5% and 10% naringin applied for 1 minute after bleaching with 35% hydrogen peroxide.⁷ The study reported that 5% naringin significantly increased bond strength compared with bleached enamel without antioxidant, with no significant impact on tooth color, suggesting naringin as a promising flavonoid antioxidant for immediate adhesive procedures after bleaching.⁷

Cranberry Extract. Cranberry extract was evaluated in three studies at concentrations of 6%.^{1,8,19} Eggula et al demonstrated that 6% cranberry solution improved but did not fully restore bond strength to the level of sodium ascorbate, with 10% sodium ascorbate proving superior in reversal of compromised bond strength following bleaching.⁸ Rahman et al reported that all four antioxidants tested (cranberry, green tea, aloe vera, and sodium ascorbate) were able to reverse compromised bond strength, with green tea performing best and cranberry performing least effectively.¹⁹ Alanazi et al found that 6% cranberry, combined with photodynamic therapy bleaching, resulted in higher SBS when combined with 10% ascorbic acid.¹

Guava Seed Extract. Shahi et al evaluated guava seed extract solutions at 10%, 20%, and 30% concentrations applied for 5, 10, and 120 minutes.³⁵ The study reported that antioxidants effectively reversed compromised bond strength of bleached enamel and that increasing concentration reduced the duration of application required.³⁵

Aloe Vera. Aloe vera was evaluated in five studies.^{14,28,33,34,38} Mena-Serrano et al found that aloe vera recovered bond strength values similar to the control group only when bonding was delayed to 7 and 14 days after bleaching, whereas sodium ascorbate was effective immediately.¹⁴ Kadiyala et al and Nari-Ratih et al both reported that aloe vera significantly improved SBS of bleached enamel.^{33,34} However, aloe vera was generally found to be inferior to grape seed extract and sodium ascorbate in its capacity to fully restore bond strength immediately after bleaching.²⁸

Pine Bark, Rosemary, and Other Extracts. Pine bark extract, evaluated in five studies, consistently improved post-bleaching bond strength.^{5,17,20,27,30} Kamat et al reported that both 10% rosemary and 10% pine bark extracts showed significantly better results when applied for 20 minutes rather than 10 minutes, confirming the importance of application duration.³⁰ Propolis was evaluated in two studies with contrasting results: Arslan et al reported that propolis tended to decrease bond strength of composite resin to enamel after intracoronal bleaching,⁴ while Srinivasan et al reported modest improvement using over-the-counter propolis.²¹ Pedicularis extract showed limited efficacy.³⁹ Suneetha et al found rosemary leaf extract and sodium ascorbate effective in reversal of bond strength, while pedicularis extract was considerably less effective.³⁹ Pomegranate peel extract improved bond strength in both studies in which it was evaluated, but did not fully restore it to control levels.^{20,37}

Quality Assessment

The methodological quality of the 41 included studies was evaluated using the JBI critical appraisal tool (Table 4). The vast majority of studies scored positively on all applicable JBI criteria, indicating satisfactory reporting of sample framework, recruitment appropriateness, sample size adequacy, description of study setting and subject characteristics, data analysis detail, use of appropriate procedures for condition verification, and appropriateness of statistical analysis. Only one study (Parinitha et al, 2024) scored "No" on two criteria related to condition assessment and statistical analysis.¹⁷ One study (Fattah et al, 2022) was not accessible. None of the included studies reported blinding of the testing machine operator, and none reported formal sample size calculations based on power analysis limitations common to in vitro dental research. The complete JBI quality assessment is presented in Table 3.

DISCUSSION

The present systematic review aimed to evaluate the evidence regarding the role of flavonoid antioxidants in restoring or enhancing resin bond strength following tooth bleaching. Forty-one studies meeting the eligibility criteria were included, encompassing a broad spectrum of natural flavonoid compounds evaluated across a variety of bleaching protocols. The findings of this review support the hypothesis that flavonoid antioxidants can improve the immediate bond strength of dental adhesives to bleached enamel, with grape seed extract/proanthocyanidin and EGCG demonstrating the most consistent and compelling evidence for bond strength restoration to non-bleached control levels.

Tooth bleaching with hydrogen peroxide or carbamide peroxide produces reactive oxygen species that persist within enamel and dentin for varying periods following treatment. These residual radicals inhibit resin monomer infiltration and polymerization, resulting in a clinically significant reduction in bond strength that is well documented across numerous in vitro studies.^{5,6,8} The inclusion of diverse study designs and flavonoid compounds in this review reflects the heterogeneity of the published literature and the ongoing interest in identifying optimal natural antioxidant agents for clinical use.

Among the flavonoids evaluated, grape seed extract (proanthocyanidin/OPCs) emerged as the most extensively studied and consistently effective agent. Proanthocyanidins exert their antioxidant activity through multiple mechanisms, including hydrogen atom donation, metal chelation, and specificity for hydroxyl free radicals.^{18, 23} The antioxidant potential of grape seed extract has been reported to be substantially greater than that of both vitamin C and vitamin E.^{18, 19,42,43,44} Across the included studies, concentrations of 3% to 10% applied for 1 to 10 minutes consistently restored or significantly improved bond strength. Xu et al demonstrated restoration of bond strength with concentrations as low as 5% applied for only 1 minute, suggesting a favorable clinical profile for grape seed extract in terms of efficiency.²⁴ The longevity of the effect was confirmed by Mena-Serrano et al, who demonstrated that bond strength values were maintained at 3-year follow-up for all antioxidant groups tested, though GSE required a delay of 7–14 days for complete restoration.¹⁴ A notable exception was found by Zhang et al, who reported that 5% proanthocyanidins applied for shorter durations were inferior to 10% sodium ascorbate for immediate bond strength recovery.²⁶

Green tea extract and its primary bioactive catechin, EGCG, represent the second most extensively investigated class of flavonoid antioxidants. Berger et al and Zhang et al both confirmed that green tea/EGCG could restore microtensile bond strength after bleaching.^{3, 25} However, a critical finding emerging from the analysis is the strong dependency of green tea efficacy on application duration. Ozelin et al demonstrated clearly that significant improvement in bond strength occurred only when green tea was applied for 60 minutes, rather than the 10–30 minute protocols commonly used in other studies.¹⁶ This dependency on application time represents an important clinical consideration, as shorter protocols may fail to produce meaningful antioxidant reversal. The differential efficacy of green tea observed by Sharafeddin et al across bleaching types effective for hydrogen peroxide but not carbamide peroxide bleaching may reflect differences in the radical load and oxidative environment produced by different peroxide agents.³⁶

Quercetin, a flavonol with well-documented antioxidant and anti-inflammatory properties, showed promising results in three studies, though the evidence remains preliminary. The unique finding reported by Lin et al that quercetin applied prior to the bonding procedure preserved immediate bond strength and enhanced aged bond strength suggests a potential role for quercetin not merely as a post-bleaching antioxidant but as a dentin bonding modifier.¹³ This mechanism may involve quercetin's ability to cross-link collagen, inhibit matrix metalloproteinases (MMPs), and reduce dentin degradation over time, an effect distinct from simple radical scavenging.¹³ This finding warrants further investigation in dedicated studies. Naringin, a citrus flavanone evaluated in the most recent study included in this review, demonstrated significant bond strength improvement at a 5% concentration applied for only 1 minute.⁷ The clinical attractiveness of naringin lies in its short application time, which compares favorably with other flavonoids and with sodium ascorbate. However, given the limited evidence from a single study, additional research is required before firm recommendations can be made.

Other flavonoid agents including guava seed extract, propolis, rosemary extract, pine bark extract, cranberry extract, and pomegranate peel extract generally improved post-bleaching bond strength to varying degrees but demonstrated less consistent restoration to non-bleached control levels.^{4,17,20,27,30,35,39} Application duration and concentration were identified as critical determinants of efficacy across multiple studies.^{16,30,35} The negative finding for propolis reported by Arslan et al, where propolis tended to decrease bond strength after intracoronal bleaching, is of clinical significance and may relate to the complex multi-component chemistry of propolis, which can include substances that interfere with resin polymerization.⁴

Sodium ascorbate, included as a comparative agent in most studies, consistently improved bond strength but did not universally restore it to non-bleached control values within the 10-minute application protocols most commonly used. This finding is consistent with previous systematic reviews on natural antioxidants.¹² While sodium ascorbate has historically been regarded as the gold standard antioxidant for this indication, several flavonoid antioxidants, particularly grape seed extract and EGCG, demonstrated equivalent or superior performance, suggesting that these natural compounds may represent viable clinical alternatives.

From a methodological standpoint, the JBI quality assessment revealed that the included studies generally satisfied the criteria for adequate sample characterization, recruitment appropriateness, and analytical rigor. However, universal limitations inherent to *in vitro* dental research were present across virtually all studies: none reported formal power calculations for sample size determination, and blinding of testing machine operators was not described. The heterogeneity in bleaching protocols, antioxidant concentrations and durations, bonding systems, and testing methodologies across studies further limits the comparability of results and precludes quantitative meta-analysis. A standardized bleaching protocol and antioxidant application protocol would significantly strengthen the evidence base in future research.

This systematic review has several limitations that must be acknowledged. First, the overwhelming majority of evidence is derived from *in vitro* studies, which, despite their methodological control, may not fully replicate the complex biological and clinical conditions of the oral environment. Second, considerable heterogeneity exists across studies in terms of bleaching agents, concentrations, application times, and antioxidant preparations, which constrains direct comparisons and generalizability. Third, while the JBI appraisal indicated generally satisfactory quality, the absence of blinding and power calculations is a consistent methodological weakness. Finally, publication bias may have influenced the available literature, with positive results more likely to be published. Future research should prioritize well-designed randomized clinical trials examining the most promising flavonoid antioxidants under standardized conditions.

CONCLUSION

The findings of this systematic review indicate that flavonoid antioxidants, when applied to bleached enamel prior to adhesive procedures, can significantly improve or restore resin bond strength compared with bleached enamel without antioxidant treatment. Grape seed extract/proanthocyanidin and epigallocatechin gallate (EGCG) demonstrated the most consistent evidence of bond strength restoration to non-bleached control levels, followed by quercetin and naringin in more recent investigations. However, given that the available evidence is predominantly derived from *in vitro* studies with variable methodological quality and heterogeneous protocols, these results must be interpreted with caution. Standardized, low-risk-of bias clinical studies and randomized clinical trials are required before firm clinical recommendations can be established. The application of flavonoid antioxidants after bleaching represents a biologically compatible and potentially clinically valuable strategy to facilitate immediate resin-based restorations, warranting continued investigation.

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Table 1: General Information of included articles

S.No	Author, Year	Aim	Sample Size	Sample Type	Type of Bleaching	Bleaching Agent	Bleaching Product	Type of Flavonoids	Comparative Group	Duration	Bonding Agent	Restorative Material
1	Alanazi et al, 2023	To assess the impact of HP and ZP activated by PDT with reversal agents (ascorbic acid, cranberry) on bond strength and enamel surface properties	60	Mandibular Molar	Extra coronal	Zinc Phthalocyanine ; Hydrogen peroxide 40%	Not mentioned	6% cranberry solution	Negative control (no bleaching); Positive Control (bleaching without antioxidant); 10% ascorbic acid	10 min	Ivoclar-Vivadent Multilink Hybrid composite bonding system	Multilink Hybrid composite, Ivoclar-Vivadent
2	Almohareb et al, 2024	To evaluate reversal of bleached enamel using SA, GTE, GSE, curcumin photosensitizer, and Er:YAG laser for adhesive strength and marginal leakage	120	First premolar	Extra coronal	35% hydrogen peroxide	Pola Office Bleach, SDI	6.5% Grape seed extract; 5% Green tea; Curcumin	Negative control; Positive Control; 10% sodium ascorbate; Er:YAG laser	10 min	Not Mentioned	Not Mentioned
3	Berger et al, 2013	To assess antioxidant effect of green tea on microtensile bond strength of composite resin to bleached enamel	42	Third molar	Extra coronal	10% carbamide peroxide	Opalescence; Ultradent, South Jordan, UT, USA	10% Green tea	Negative control; Positive Control; 10% sodium ascorbate	1 hour	Adper Single Bond 2; 3M ESPE	Z350; 3M ESPE
4	Arslan S et al, 2023	To assess the effect of propolis as antioxidant on bond strength after intracoronal bleaching	160	Maxillary Central Incisors	Intra Coronal	Sodium perborate; 37% Carbamide; 35% Hydrogen peroxide	Sigma Aldrich; Merck; Whitess SuperEndo; Opalescence Endo	10% Propolis	Negative control; Positive Control; 10% Sodium ascorbate	10 min	Adper Single Bond 2 (3M ESPE)	Clearfil Majesty Aesthetic (Kuraray)
5	Bhasker N et al, 2024	To evaluate and compare effects of different antioxidants on shear bond strength of composite resin to bleached enamel	90	Maxillary Central Incisors	Extra coronal	40% Hydrogen peroxide	Opalescence Boost, Ultradent, USA	5% grape seed extract; 5% pine bark extract	Negative control; Positive Control; 10% sodium ascorbate	10 min	Adper Single Bond (3M ESPE)	Filtek Z 350 XT, 3M ESPE
6	Brock T et al., 2024	To evaluate influence of antioxidants (astaxanthin, resveratrol, winter's bark, green tea, yerba mate) on bond strength of bleached enamel with nanohybrid composite	132	Bovine incisors	Extra coronal	35% Hydrogen peroxide	Whitess HP®, FGM, Brazil	10% winter's bark; 10% Green tea; 10% Yerba mate	Negative control; Positive Control; 10% resveratrol	5, 10, 15, 30, and 60 min	Ambar™	Opallis™
7	Carvalho G.L.M et al, 2025	To evaluate effect of flavonoid-based antioxidants on shear bond strength after in-office bleaching and compare with 10% sodium ascorbate	50	Bovine incisors	Extra coronal	35% Hydrogen peroxide	Whitess HP, FGM	5% naringin; 10% naringin	Control (no bleaching); Control (bleaching without antioxidant); 10% sodium ascorbate	1 min	Single Bond Universal, 3M	Filtek Bulk Fill Flowable Restorative (3M)
8	Eggula A et al, 2019	To evaluate neutralizing effect of 6% cranberry solution on bond strength of bleached enamel compared to 10% sodium ascorbate	64	Premolars	Extra coronal	40% Hydrogen peroxide	Opalescence Boost, Ultradent	6% cranberry solution	Negative control; Positive Control; 10% sodium ascorbate	10 min	Prime & Bond® NT, Dentsply	Filtek Z350, 3M ESPE
9	Elawsya M et al, 2021	To investigate effect of different antioxidants on bond strength of resin composite to bleached enamel	110	Maxillary central incisors	Extra coronal (both HP and CP)	35% Carbamide peroxide; 40% Hydrogen peroxide	WHITEsmile GmbH, Germany	10% Green tea; 10% Grape seed extract	Negative control; Positive Control; 10% sodium ascorbate; 5% Alpha-lipoic acid	10 min	Adper Single Bond 2	Filtek Z250 XT; 3M ESPE
10	Fatah Z., et al, 2022	To evaluate effect of tannic acid and quercetin on micro-shear bond strength of two resin cements to dentin following internal bleaching	80	Maxillary central incisors	Intra Coronal	Not mentioned	Not mentioned	Quercetin	Tannic acid	Not mentioned	Not mentioned	Not mentioned
11	Gündođdu et al, 2020	To assess effect of four antioxidant protocols on shear bond strength of resin-based composite to bleached enamel and dentin	280	Bovine Incisors	Extra coronal	40% Hydrogen peroxide	Opalescence Boost PF, Ultradent, USA	Green Rosemary tea;	Negative control; Positive Control; 10% sodium ascorbate	10 min	Adper Single Bond 2, 3M ESPE	Filtek Z250, 3M ESPE
12	Gupta S., et al, 2021	To evaluate antioxidant properties of 10% amla extract in reversing compromised bond strength and color stability	90	Maxillary central incisor	Extra coronal	Hydrogen peroxide	NICE Chemical Laboratory Supplies, India	10% Amla	Negative control; Positive Control; Elsenz	10 min	Ivoclar Tetric-N-Bond	Ivoclar Vivadent tetric-n-flow
13	Lin X.J., et al, 2022	To examine effect of quercetin pretreatment on the bond strength of bleached dentin	112	Third molars	Intra coronal	40% Hydrogen peroxide	Opalescence Endo, Ultradent	Quercetin	Negative control; Positive Control	2 min	Panavia V5 tooth primer (Kuraray)	Panavia V5, Kuraray
14	Mena-Serrano A., et al, 2023	To assess effect of antioxidant application on bond strength of bleached enamel after 24 hours and 3 years of water storage	84	Bovine teeth	Extra coronal	35% Hydrogen peroxide	Whitess HP, FGM, Brazil	Grape seed extract; Aloe vera	Negative control; Positive Control; 10% sodium ascorbate	10 min	One Coat Bond SL, Coltene/Whaledent	Brilliant NG, Coltene/Whaledent
15	Moradian M., et al, 2022	To compare effects of post-bleaching sodium ascorbate, alpha-tocopherol, and quercetin on shear bond strength of composite resin	60	Maxillary first premolars	Extra coronal	40% Hydrogen peroxide	Filtek Z 250; 3M ESPE	1% Quercetin; 10% alpha-tocopherol	Negative control; Positive Control; 10% sodium ascorbate	10 min	Adper single bond (3M ESPE)	Filtek Z 250; 3M ESPE
16	Ozelin A.A., et al, 2014	To evaluate the impact of green tea application duration on bond strength following enamel bleaching	80	Third Molars	Extra coronal	10% carbamide peroxide	Opalescence; Ultradent	Green tea	Negative control; Positive Control; 10% sodium ascorbate	15, 30, 60 min	Adper Single Bond 2; 3M ESPE	Z350; 3M ESPE
17	Parinitha M, 2024	To assess effect of herbal antioxidants on push-out bond strength of resin-based composite to dentin after intracoronal bleaching	60	Mandibular premolar	Intra coronal	35% hydrogen peroxide; sodium perborate	Not mentioned	10% Green tea extract; 10% Pine bark extract	Negative control; Positive Control; Sodium ascorbate	30 seconds	Tetric N Bond	Ivoclar Vivadent
18	Radhakrishnan R., et al, 2021	To assess color and surface changes in enamel, and micro-shear bond strength after bleaching with HP and strawberry extract	60	Bovine teeth	Extra coronal	35% hydrogen peroxide	Not mentioned	2% Strawberry extract; 5% Proanthocyanidin	Negative control; Positive Control	Not mentioned	Adper Easy One, 3M ESPE	Filtek Z350XT, 3M ESPE

19	Rahman H, et al, 2021	To evaluate antioxidant activity of herbal antioxidants including cranberry, green tea, aloe vera, and sodium ascorbate in reversing bond strength in bleached enamel	120	Maxillary central incisor	Extra coronal	15% Carbamide peroxide	NUPRO white gold, Dentsply	6% cranberry extract; 10% green tea; 50% aloe vera	Negative control; Positive Control; Sodium ascorbate	10 min	Prime & Bond NT	ESTHET.X HD
20	Mukka P., et al, 2016	To restore lost bond strength by evaluating shear bond strength of composite resin to bleached enamel using antioxidants	50	Maxillary central incisor	Extra coronal	40% hydrogen peroxide	Opalescence Boost, Ultradent, USA	5% grape seed bark extract; 5% pine bark extract; 5% pomegranate peel extract	Negative control; Positive Control	10 min	Adper Easy One, 3M ESPE	Filtek Z350 XT, 3M ESPE
21	Srinivasan S., et al, 2022	To compare and assess shear bond strength of composite resin after application of three natural antioxidants on bleached enamel	36	Anterior teeth	Extra coronal	35% hydrogen peroxide	Pola office, SDI Limited	Vitamin E; Olive oil; Propolis	Negative control; Positive Control	10 min	Te-Econom Bond (Ivoclar Vivadent)	Tetric N-Ceram, Ivoclar Vivadent
22	Suvarna Y et al, 2023	To evaluate effect of 3% grape seed extract on bond strength of bleached enamel, comparing with natural and commercial bleaching agents	40	Maxillary central incisor	Extra coronal	35% hydrogen peroxide; Sweet potato extract	Pola office, SDI Limited	3% grape seed extract	Negative control; Positive Control	10 min	Adper Single Bond, 3M ESPE	Spectrum composite, Dentsply
23	Vidhya S et al, 2011	To assess neutralizing effect of grape seed extract (OPCs) on bond strength of bleached enamel	70	Maxillary central incisor	Extra coronal	38% hydrogen peroxide	Opalescence Xtra Boost, Ultradent	5% Grape seed extract	Negative control; Positive Control; 10% Sodium ascorbate	10 min	Adper Single Bond, 3M ESPE	Filtek Z350, 3M ESPE
24	Xu Y., et al, 2018	To determine whether grape seed extract can restore shear bond strength of total-etch adhesive to enamel after bleaching	360	Bovine teeth	Extra coronal	35% hydrogen peroxide	Beyond, Puyang, China	2.5%, 5%, 10%, 15% Grape seed extract	Negative control; Positive Control	1 min	All-Bond 3, Bisco, USA	Filtek Z350, 3M ESPE
25	Zhang D., et al, 2021	To compare effects of remineralization fluid, 10% sodium ascorbate, EGCG, and 75% ethanol on bonding strength after bleaching	120	Bovine incisors	Extra coronal	40% hydrogen peroxide	Opalescence Xtra Boost 40%, Ultradent	10% EGCG solution; 20% EGCG solution	Negative control; Positive Control; 10% Sodium ascorbate	60 min	Single Bond Universal, 3M	Bisco, Inc., USA
26	Zhang H., et al, 2019	To compare the effects of two antioxidants on enhancing the bond strength of resin to bleached enamel	48	Maxillary central incisor	Extra coronal	35% hydrogen peroxide	VIVA Technology International, USA	5% proanthocyanidins	Negative control; Positive Control; 10% Sodium ascorbate	30, 60, 120 min	Not mentioned	Not mentioned
27	Subramonian et al, 2015	To evaluate impact of sodium ascorbate, grape seed extract, and pine bark extract on shear bond strength of composite resin to bleached enamel	90	Maxillary premolars	Extra coronal	35% hydrogen peroxide	Pola Office Plus, SDI, Australia	10% grape seed extract; pine bark extract	Negative control; Positive Control; 10% Sodium ascorbate	10 min	Adper Single Bond, 3M ESPE	Filtek Z 250, 3M ESPE
28	Nair et al, 2019	To investigate effect of three different antioxidant treatments on bond strength of composite resin to bleached enamel	90	Maxillary anterior	Extra coronal	35% carbamide peroxide	Ultra White, Ammdent	6.5% proanthocyanidin; 50% Aloe vera	Negative control; Positive Control; 10% Sodium ascorbate	10 min	Not mentioned	3M ESPE, Filtek Z350XT
29	Srivastava et al, 2021	To evaluate effect of 10% alpha-tocopherol and 5% grape seed extract on microhardness and shear bond strength to bleached human dentin	200	Premolars	Extra coronal	35% hydrogen peroxide	Not mentioned	5% proanthocyanidin seed extract	Negative control; Positive Control; 10% alpha-tocopherol	10 min	Adper Single Bond 2, 3M ESPE	Z100 Restorative, 3M ESPE
30	Kamat et al, 2024	To evaluate and compare effect of herbal antioxidants on SBS of composite resin to bleached enamel at different time intervals	60	Maxillary incisors	Extra coronal	35% hydrogen peroxide	Pola Office Plus	10% Pine bark extract; 10% Rosemary extract	Negative control; Positive Control	10, 20 min	Tetric N-Bond, Ivoclar Vivadent	Te-Econom Plus Composite, Ivoclar Vivadent
31	Lokhande et al, 2019	To evaluate and compare effect of 5% proanthocyanidin and 30% alpha-tocopherol on bond strength of composite resin to bleached enamel	60	Maxillary central incisors	Extra coronal	38% hydrogen peroxide	Opalescence Xtra Boost, Ultradent	5% Proanthocyanidin	Negative control; Positive Control; 30% alpha-tocopherol	10 min	Adper Single Bond, 3M ESPE	Filtek Z 250, 3M ESPE
32	Halkai et al, 2024	To evaluate antioxidant effects of selenium alone and in combination with alpha-tocopherol and green tea on SBS following in-office bleaching	70	Single rooted premolar	Extra coronal	38% hydrogen peroxide	Pola Office, SDI Limited, USA	Green tea; Alpha tocopherol	Negative control; Positive Control; 10% selenium; combinations	10 min	Tetric N-Bond Universal	Fusion, Prevest Denpro, India
33	Anirudh Kadiyala et al, 2015	To compare and evaluate effect of Aloe Vera with 10% sodium ascorbate on shear bond strength of composite resin to bleached human enamel	50	Maxillary central incisors	Intra coronal	35% Carbamide Peroxide	Opalescence, Ultradent	Aloe vera	Negative control; delayed bonding week; 10% Sodium Ascorbate; immediate bonding without antioxidant	30 min	Single Bond 2, 3M ESPE	Z 250XT, 3M ESPE
34	Nari-Rath D et al, 2019	To determine effect of antioxidants on shear bond strength of composite resin to enamel following extra-coronal bleaching with 40% HP	70	Premolars	Extra coronal	40% hydrogen peroxide	Opalescence Xtra Boost 40%, Ultradent	10% Green tea; 10% Aloe vera	Bleaching only immediately; delayed 2 weeks; 10% sodium ascorbate; 10% alpha-tocopherol	Not mentioned	XP Bond, Dentsply deTrey	Ceram X Duo, Dentsply deTrey
35	Shahi et al, 2020	To evaluate and compare effect of guava seed extract solutions in various concentrations on shear bond strength of composite resin to bleached enamel	55	Maxillary incisors	Extra coronal	37.5% hydrogen peroxide	Pola office, SDI, Australia	10%, 20%, 30% guava seed extract solution	Positive control; Negative control	5, 10, 120 min	Not mentioned	Not mentioned
36	Sharafeddin et al, 2016	To assess green tea extract on shear bond strength of resin composite to in-office and home-bleached dentin	40	Incisors	Extra coronal	38% hydrogen peroxide; 15% carbamide peroxide	Opalescence, Ultradent	5% green tea extract	Carbamide Peroxide; CP + Green Tea; HP; HP + Green Tea	10 min	Adper Single Bond, 3M ESPE	Filtek Z350, 3M ESPE
37	Sharafeddin et al, 2015	To assess effect of different antioxidants on shear bond strength of composite resin to home-bleached enamel	60	Maxillary incisors	Extra coronal	15% carbamide peroxide gel	Opalescence 15% PF, Ultradent	10% pomegranate peel; 10% grape seed extract; 5% green tea; aloe vera leaf gel	10% sodium ascorbate; pomegranate peel; grape seed extract;	10 min	Adper Single Bond, 3M ESPE	Filtek Z350, 3M ESPE

38	Abraham et al, 2013	To evaluate effect of grape seed extract (OPCs) on bond strength of composite resin to bleached enamel using 5th and 7th generation bonding agents	80	Maxillary incisors	Extra coronal	38% hydrogen peroxide gel	Opalescence Xtra Boost	5% proanthocyanidin solution	green tea; aloe vera	10 min	Prime & Bond NT; Xeno V	Not mentioned
39	Suneetha R et al, 2014	An In Vitro Comparative Study of SBS of composite resin to bleached enamel using synthetic and herbal antioxidants	50	Single rooted human teeth	Extra coronal	10% carbamide peroxide gel	Opalescence, Ultradent	Rosemary extract; Pedicularis extract		10 min	Not mentioned	Filtek Z350, 3M ESPE
40	Khamverdi et al, 2016	To assess effect of green tea, sodium ascorbate, sage and grape seed extract on bond strength of composite to bleached enamel	90	Maxillary anteriors	Extra coronal	40% hydrogen peroxide gel	Power Whitening YF, White Smile GmbH, Germany	10% sage solution; 5% proanthocyanidin		10 min	Adper Single Bond, 3M ESPE	Filtek Z250, 3M ESPE
41	Khamverdi et al, 2013	To determine effect of epigallocatechin gallate (EGCG) on shear bond strength of composite resin to bleached enamel	90	Maxillary anteriors	Extra coronal	30% hydrogen peroxide gel	Opalescence Xtra Boost, Ultradent	600, 800 and 1000 µmol EGCG	Control (no bleaching); + 24h storage; 7 days storage; EGCG 10/20 min	10, 20 min	Adper Single Bond Plus, 3M ESPE	Filtek Z250, 3M ESPE

Table 2: Methodology Assessment

S.No	Author, Year	Technique for Identification	Storage before use	Storage after bleaching	Storage after antioxidant	Storage after restoration	Primary Outcome	Secondary Outcome	Conclusion
1	Alanazi et al, 2023	Universal testing machine; Vickers hardness tester	3 months	Not mentioned	Not mentioned	Not mentioned	Shear bond strength	Surface microhardness; Microleakage; Failure mode	ZP activated by PDT with ascorbic acid showed the highest SBS and SMH bond
2	Almohareb et al, 2024	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	1 day	Shear bond strength	Failure mode	CP, GTE and GSE showed improves bond strength
3	Berger et al, 2013	Microtensile machine	1 month	14 days	1 hour	1 day	Microtensile bond strength	Failure mode	Green tea extract can effectively reverse the bond strength.
4	Arslan S et al, 2023	Universal testing machine	1 week	Not mentioned	Not mentioned	1 day	Shear bond strength	—	Propolis tends to decrease the bond strength.
5	Bhasker N et al, 2024	Universal testing machine	Not mentioned	24 hours; 2 weeks	Not mentioned	Not mentioned	Shear bond strength	Failure mode	Grape seed extract and pine bark extract effectively reversed the bond strength.
6	Brock T et al., 2024	Universal testing machine	1 week	Immediately	Immediately	1 week	Microtensile bond strength	Colour evaluation; Failure mode; Enamel surface morphology	Experimental antioxidants showed improved immediate bond strength.
7	Carvalho G.L.M et al, 2025	Universal testing machine	60 days	Not mentioned	Not mentioned	Not mentioned	Shear bond strength	Colour evaluation	Naringin significantly increased bond strength.
8	Eggula A et al, 2019	Universal testing machine	Not mentioned	24 hours; 2 weeks	Not mentioned	24 hours	Shear bond strength	Failure mode	SA solution showed superior bond strength in comparison to CB solution.
9	Elawsya M et al, 2021	Universal testing machine	3 months	Not mentioned	Not mentioned	Not mentioned	Micro-shear bond strength	—	Sodium ascorbate, GSE, green tea extract restored bond strength while alpha-lipoic acid was not able to reverse the bond strength
10	Fattah Z., et al, 2022	Not mentioned	Not mentioned	Not mentioned	Not mentioned	24 hours	Micro-shear bond strength	—	No significant difference was seen between quercetin and tannic acid for reversing bond strength
11	Gündogdu et al, 2020	Shear test device	1 week	Immediate; 2 weeks	Not mentioned	24 hours	Shear bond strength	Colour stability	All antioxidant other than the combination of green tea and rosemary showed improved bond strength
12	Gupta S., et al, 2021	Universal testing machine	Not mentioned	Not mentioned	1 week; 2 weeks	48 hours	Shear bond strength	Colour stability	Amla solution was not able to restore the bond strength
13	Lin X.J., et al, 2022	Universal testing machine	Not mentioned	24 hours; Thermocycling 10,000 cycles	Not mentioned	24 hours	Shear bond strength	Colour stability	Quercetin showed immediate bond strength improvements
14	Mena-Serrano A., et al, 2023	Microtensile bond testing jig with digital caliper	7 days	24 hours; 7 days; 14 days	Not mentioned	24 hours; 3 years	Microtensile bond strength	—	Immediate bond strength was recovered after antioxidant application
15	Moradian M., et al, 2022	Universal testing machine	60 days	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Quercetin increased bond strength
16	Ozelin A.A., et al, 2014	Microtensile bond testing jig	30 days	Not mentioned	Not mentioned	24 hours	Shear bond strength	Failure mode	Bond strength values with antioxidants applications
17	Parinitha M, 2024	Universal testing machine	Not mentioned	5 days	Not mentioned	24 hours	Push out bond strength	Colour stability	Bond strength was improved by10% pine bark

S.No	Author, Year	Technique for Identification	Storage before use	Storage after bleaching	Storage after antioxidant	Storage after restoration	Primary Outcome	Secondary Outcome	Conclusion
18	Radhakrishnan R., et al, 2021	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Micro-shear bond strength	Colour stability	Strawberry extract can effectively improve bond strength
19	Rahman H., et al, 2021	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Microtensile bond strength	—	Green tea, aloe vera, sodium ascorbate, and cranberry improved bond strength.
20	Mukka P., et al, 2016	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	Immediately	Shear bond strength	—	5% grape seed extract, 5% pine bark extract, 5% pomegranate peel extract reduced SBS of composite resin
21	Srinivasan S., et al, 2022	Universal testing machine	Not mentioned	Immediate; 3 weeks	Not mentioned	24 hours	Shear bond strength	—	All antioxidants showed the improved shear bond strength
22	Suvarna Y et al, 2023	Universal testing machine	1 week	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	3% GSE showed increased SBS
23	Vidhya S et al, 2011	Universal testing machine	Not mentioned	Immediate; 2 weeks	Not mentioned	24 hours	Shear bond strength	Failure mode	Grape seed extract showed significantly increases bond strength
24	Xu Y., et al, 2018	Universal testing machine	1–1.5 years	Not mentioned	Not mentioned	24 hours; Thermocycling 5000 cycles	Shear bond strength	Failure mode	GSE showed improvedSBS after bleaching
25	Zhang D., et al, 2021	Microtensile device	4 years	Not mentioned	Not mentioned	24 hours	Microtensile bond strength	Failure mode	EGCG showed improved bond strength.
26	Zhang H., et al, 2020	Universal testing machine	30 days	Not mentioned	Not mentioned	24 hours	Microtensile bond strength	—	Sodium ascorbate showed improved bond strength in comparison proanthocyanidins
27	Subramonian et al, 2015	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Pine bark extract showed significantly improved bond strength
28	Nair et al, 2019	Universal testing machine	Not mentioned	Immediate; 2 weeks	Not mentioned	Not mentioned	Shear bond strength	—	Grape seed extracts were superior to sodium ascorbate and Aloe vera in reversing the bond strength
29	Srivastava et al, 2021	Universal testing machine	Not mentioned	Immediate; 2 weeks	Not mentioned	24 hours	Shear bond strength	Microhardness test	Alpha-tocopherol and grape seed showed improved dentinal surface microhardness and SBS
30	Kamat et al, 2024	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Rosemary and pine bark extracts showed improved SBS
31	Lokhande et al, 2019	Universal testing machine	Not mentioned	Not mentioned	Immediately	Not mentioned	Shear bond strength	—	Proanthocyanidin showed improvedbond strength
32	Halkai et al, 2024	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Combination of selenium with green tea and alpha tocopherol showed effective SBS
33	Anirudh Kadiyala et al, 2015	Universal testing machine	3 weeks	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Aloe Vera and Sodium Ascorbate showed better bond strength
34	Nari-Ratih D et al, 2019	Universal testing machine	1 month	Immediately; After 2 weeks	Not mentioned	24 hours	Shear bond strength	—	Sodium ascorbate, alpha-tocopherol, green tea and aloe vera were effective in reversing the shear bond strength.
35	Shahi et al, 2020	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	Not mentioned	Shear bond strength	—	All Antioxidants were effective
36	Sharafeddin et al, 2016	Universal testing machine	Not mentioned	Not mentioned	Immediately	24 hours	Shear bond strength	—	Green tea had no significant effect on SBS with carbamide peroxide, but significantly increased SBS hydrogen peroxide
37	Sharafeddin et al, 2015	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	All antioxidants used had the same effect on SBS
38	Abraham et al, 2013	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Grape seed extract was effective in improving the bond strength.
39	Suneetha R et al, 2014	Universal testing machine	Not mentioned	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	Rosemary leaf extracts and sodium ascorbate were effective; pedicularis extract was not effective
40	Khamverdi et al, 2016	Universal testing machine	3 months	Not mentioned	Not mentioned	24 hours	Shear bond strength	—	All antioxidants used were effective
41	Khamverdi et al, 2013	Universal testing machine	3 months	Immediately; 7 days	Not mentioned	24 hours	Shear bond strength	—	EGCG showed increased bond strength.

Table 3: Joanna Briggs' quality assessment criteria.

S.No	Author and Year	Was the framework of sample appropriate for the targeted population?	Was the recruitment process conducted appropriately?	Was the sample size adequate?	Was the study setting and subject characteristics clearly described?	Was data analysis conducted with sufficient detail regarding sample identification?	Were appropriate procedures used to verify the study condition?	Was the study condition assessed appropriately and reliably for each participant?	Was the response rate satisfactory, and if not, was the lower response rate managed appropriately?	Was the statistical analysis appropriate and well-suited for the study?
1	Alanazi et al. 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
2	Almohareb et al. 2024	Yes	Yes	Yes	No	Yes	Yes	Yes	NA	Yes
3	Berger et al. 2013	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
4	Arslan S et al. 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
5	Bhasker N et al. 2024	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
6	Brook T et al., 2024	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
7	Carvalho et al. 2025	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
8	Eggula A et al. 2019	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
9	Elawsya M et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
10	Fattah Z., et al. 2022	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	Gündođdu et al. 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
12	Gupta S., et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
13	Lin X.J., et al. 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
14	Mena-Serrano et al. 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
15	Moradian M., et al. 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
16	Ozelin A.A., et al. 2014	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
17	Parinitha M, 2024	Yes	Yes	Yes	Yes	Yes	Yes	No	NA	No
18	Radhakrishnan et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
19	Mukka P., et al. 2016	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
20	Rahman H., et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
21	Srinivasan S., et al. 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
22	Suvarna Y et al. 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
23	Vidhya S et al. 2011	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
24	Xu Y., et al. 2018	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
25	Zhang D., et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
26	Zhang H., et al. 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
27	Subramonian et al. 2015	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
28	Nair et al. 2019	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
29	Srivastava et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
30	Kamat et al. 2024	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
31	Lokhande et al. 2019	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
32	Halkai et al. 2024	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
33	Kadiyala et al. 2015	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
34	Nari-Ratih D et al. 2019	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
35	Shahi et al. 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
36	Sharafeddin et al. 2016	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
37	Sharafeddin et al. 2015	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
38	Abraham et al. 2013	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
39	Suneetha R et al. 2014	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
40	Khamverdi et al. 2016	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
41	Khamverdi et al. 2013	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes

Figure 1: PRISMA Flow chart on number of articles selected in the systematic review based on eligibility criteria

