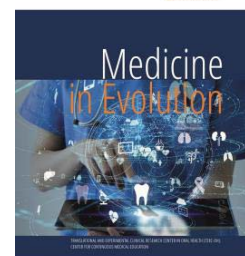


Can Bioactivity Preserve Esthetics? Color Stability of Resin Composites Following Exposure to Everyday Beverages

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Abstract

1. Background/Objectives: Resin-based composites are widely used restorative materials; however, their long-term esthetic stability may be affected by exposure to commonly consumed beverages. This in vitro study aimed to evaluate and compare the color stability of a bioactive resin composite (Predicta® Bioactive Bulk Fill) and a conventional microhybrid resin composite (Filtek™ Z250 Universal Restorative) following immersion in coffee, Coca-Cola, and Nestea. 2. Methods: Forty disc-shaped specimens (n = 40) were fabricated, polished, and randomly allocated to four immersion media (distilled water, coffee, Coca-Cola, and Nestea; n = 5/group). After seven days of immersion at 37°C, color measurements were performed using a VITA Easyshade V spectrophotometer according to the CIE Lab* color system. Descriptive statistics and two-way ANOVA were applied, with statistical significance established at $p < 0.05$. 3. Results: Coffee produced the greatest color alterations in both materials, resulting in the highest increases in b^* values and estimated color differences. Predicta Bioactive showed consistently greater discoloration than Filtek Z250 in all immersion media. The highest estimated ΔE^*ab values were recorded after coffee immersion (15.77 for Predicta Bioactive and 7.48 for Filtek Z250), followed by Nestea and Coca-Cola. 4. Conclusion: Beverage exposure significantly influenced color stability, with Predicta Bioactive showing greater discoloration than Filtek Z250 and coffee exhibiting the highest staining potential.

Keywords: Dental Resin Composites; Bioactive Materials; Color Stability; Beverage Consumption; Surface Properties; Aging; In Vitro Techniques

INTRODUCTION

Resin-based composites remain the most widely used direct restorative materials in contemporary dentistry due to their favorable esthetic properties, adhesive bonding capability, and continuous improvements in mechanical performance. Recent advances in restorative biomaterials have expanded the concept of dental composites beyond passive defect replacement, leading to the development of bioactive restorative materials designed to interact dynamically with the oral environment through ion release, remineralization potential, and antimicrobial activity. These materials aim not only to restore lost tooth structure but also to contribute to the prevention of secondary caries and the maintenance of oral health. Recent reviews have highlighted the growing interest in bioactive resin composites as a promising generation of restorative materials capable of combining functional, biological, and esthetic benefits [1-3].

Bioactive resin composites typically incorporate bioactive glass, calcium phosphate compounds, fluoride-releasing fillers, or other ion-releasing particles that promote remineralization and enhance the biological performance of restorations. Their ability to respond to changes in the oral environment has led to their classification among “smart” dental materials. Nevertheless, despite these advantages, concerns remain regarding the long-term stability of their physical and esthetic properties, particularly when exposed to the complex chemical challenges encountered in everyday life [4-6].

Color stability is one of the most important determinants of the clinical success of esthetic restorations. Patients increasingly expect restorations to maintain their original appearance over time, especially in visible areas of the dentition. However, discoloration remains a common reason for restoration replacement. Color changes may result from intrinsic factors, such as resin matrix degradation and water sorption, as well as extrinsic factors including exposure to dietary pigments and acidic beverages. The extent of discoloration depends on material composition, filler characteristics, degree of conversion, surface properties, and environmental conditions [7,8].

Modern dietary habits expose restorative materials to a wide range of staining and erosive agents. Coffee is recognized as one of the most chromogenic beverages due to its high concentration of yellow-brown pigments and tannins, while carbonated soft drinks such as Coca-Cola may promote surface degradation through their acidic pH. Ready-to-drink iced teas, including Nestea®, combine both acidic and chromogenic characteristics, potentially affecting the optical performance of resin-based restorations. Several studies have demonstrated that prolonged exposure to these beverages can significantly alter the color and surface characteristics of composite materials [9-12].

The optical behavior of resin composites is strongly influenced by their chemical composition and microstructure. The organic matrix, filler content, filler size distribution, refractive index matching, and water sorption characteristics all contribute to the overall color stability of restorative materials. Exposure to aqueous environments may promote water uptake and hydrolytic degradation of the resin matrix, facilitating the penetration and adsorption of exogenous pigments. Consequently, materials exhibiting increased hydrophilicity or greater water sorption may be more susceptible to clinically perceptible discoloration over time [8,13].

Bioactive restorative materials introduce additional complexity because their therapeutic mechanisms often rely on ion exchange and interaction with the surrounding oral environment. While these features may provide biological benefits such as remineralization and pH buffering, they may also influence surface integrity, water sorption, and optical stability. Long-term ion release and exposure to aqueous media have been associated with

alterations in the physicochemical properties of certain bioactive materials, raising questions regarding their ability to maintain esthetic performance under everyday dietary challenges [3,14].

From a clinical perspective, color alterations exceeding perceptibility or acceptability thresholds may compromise patient satisfaction and lead to restoration replacement despite the absence of structural failure. Therefore, evaluating the color stability of emerging bioactive composites is essential not only for understanding their material behavior but also for assessing their long-term clinical suitability in esthetically demanding situations. As the use of bioactive restorative materials continues to expand, evidence regarding their resistance to staining and discoloration becomes increasingly relevant for evidence-based material selection in daily dental practice [15,16].

Although numerous investigations have evaluated the staining susceptibility of conventional resin composites, evidence regarding the esthetic behavior of bioactive restorative composites remains limited and sometimes contradictory. The ion-releasing nature and increased water interaction associated with some bioactive materials may influence their resistance to discoloration. Consequently, direct comparisons between bioactive and conventional composites under identical staining conditions are necessary to better understand their long-term esthetic performance and clinical applicability [14,15].

Aim and objectives

The aim of this *in vitro* study was to evaluate and compare the color stability of a bioactive restorative composite (Predicta® Bioactive Bulk Fill, Parkell Inc., Brentwood, New York, USA) and a conventional resin-based composite (Filtek™ Z250 Universal Restorative, 3M Oral Care, St. Paul, Minnesota, USA) after immersion in commonly consumed beverages. Given the increasing clinical use of bioactive restorative materials and the growing demand for long-term esthetic performance, understanding their behavior under staining conditions is of particular clinical relevance.

The specific objectives of the study were to assess the color changes exhibited by both restorative materials after immersion in coffee, Coca-Cola, and Nestea; to compare the staining susceptibility of the bioactive and conventional composites; to evaluate the influence of different beverages on the esthetic behavior of the investigated materials; and to determine whether the bioactive composite demonstrated superior color stability compared with the conventional composite under identical experimental conditions.

The null hypothesis tested was that neither the restorative material nor the immersion medium would significantly influence the color stability of the investigated resin composites after seven days of exposure.

MATERIAL AND METHODS

This *in vitro* study evaluated the color stability of two commercially available resin-based restorative materials: a bioactive resin composite, Predicta® Bioactive Bulk Fill (Parkell Inc., Brentwood, NY, USA), and a conventional microhybrid resin composite, Filtek™ Z250 Universal Restorative (3M Oral Care, St. Paul, MN, USA). Both materials were used in shade A2 to eliminate the influence of shade variability on color measurements. Predicta Bioactive was selected because of its ion-releasing and remineralizing potential, while Filtek Z250 was chosen as a well-established conventional composite with documented clinical performance and color stability. The main characteristics of the investigated materials are presented in Table 1.

Table 1. Characteristics of the investigated restorative materials

Material	Manufacturer	Shade	Composite Type	Resin Matrix	Filler Content
Predicta® Bioactive Bulk Fill	Parkell Inc., Brentwood, NY, USA	A2	Bioactive composite	Modified urethane dimethacrylate resin matrix with ionic resin components	Bioactive glass, calcium phosphate and silica fillers (~74 wt%)
Filtek™ Z250 Universal Restorative	3M Oral Care, St. Paul, MN, USA	A2	Microhybrid composite	Bis-GMA, UDMA, Bis-EMA	Zirconia/Silica fillers (~82 wt%)

A total of forty disc-shaped specimens were fabricated, with twenty specimens prepared from each restorative material. The sample size was determined based on the experimental design, which included two restorative materials and four immersion media (distilled water, coffee, Coca-Cola, and Nestea), resulting in eight experimental groups. Five specimens were allocated to each group (n = 5), yielding a total of forty specimens (2 materials × 4 immersion conditions × 5 specimens). This sample size is consistent with previous in vitro studies investigating the color stability of resin-based restorative materials following exposure to staining beverages and was considered sufficient to detect clinically relevant differences among groups while maintaining experimental feasibility. The selected sample size was also in accordance with similar in vitro investigations[11] evaluating discoloration and optical changes in dental resin composites, where group sizes ranging from five to ten specimens are commonly employed.

Standardized cylindrical plexiglass molds measuring 10 mm in diameter and 2 mm in thickness were used for specimen preparation. The composite material was inserted into the mold in a single increment and covered with a Mylar strip to obtain a smooth surface and minimize the oxygen-inhibited layer. A glass slide was gently pressed over the strip to remove excess material and standardize specimen thickness.

Polymerization was performed using a LED curing unit (Bluephase G2, Ivoclar Vivadent, Schaan, Liechtenstein) operating at an intensity of 1200 mW/cm². Each specimen was light-cured for 40 s on both sides, with the curing tip positioned approximately 1 mm from the specimen surface. The output intensity of the curing unit was periodically verified using a calibrated radiometer according to the manufacturer's recommendations.

After polymerization, all specimens were removed from the molds and visually inspected to exclude samples presenting voids, cracks, or surface defects.

To standardize surface conditions prior to color assessment, all specimens were polished using a multi-step polishing system (Sof-Lex™, 3M ESPE Dental Products, St. Paul, MN, USA) under low-speed rotation. Polishing was performed sequentially using coarse, medium, fine, and superfine discs for approximately 20 s per step. Following polishing, specimens were ultrasonically cleaned in distilled water for 5 min to remove polishing residues and subsequently stored in distilled water at 37°C for 24 h before baseline color measurements.

The specimens were randomly assigned to four experimental groups according to the immersion medium:

- Distilled water (control)
- Coffee
- Coca-Cola
- Nestea®

For each restorative material, five specimens were included in each experimental group (n = 5).

Coffee solution was prepared daily by dissolving 5 g of instant coffee in 150 mL of boiling distilled water. Coca-Cola® (The Coca-Cola Company, Atlanta, GA, USA) and

Nestea® iced tea were used directly from newly opened containers to ensure chemical consistency throughout the experiment.

All immersion solutions were maintained at 37°C to simulate oral conditions. Specimens were individually immersed in sealed containers containing 20 mL of the corresponding solution and stored continuously for 7 consecutive days.

To minimize variations in chemical composition and staining capacity, all solutions were renewed every 24 h. Control specimens were stored in distilled water at 37°C throughout the entire experimental period.

Color evaluation was performed using a digital spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Säckingen, Germany) according to the Commission Internationale de l'Éclairage (CIE) L*a*b* color system. Measurements were obtained after specimen preparation and following seven days of immersion in the experimental media. For each specimen, three consecutive measurements were recorded and averaged to minimize measurement variability.

The color characteristics of the investigated materials were assessed using the three-dimensional CIELAB color space, where L* represents lightness, a* indicates the red–green chromatic axis, and b* corresponds to the yellow–blue chromatic axis (Figure 1). Changes in these coordinates were used to evaluate the influence of the immersion media on the optical behavior of the tested restorative materials. Particular attention was given to variations in the b* coordinate, as increases in positive b* values are commonly associated with clinically perceptible yellow discoloration induced by staining beverages.

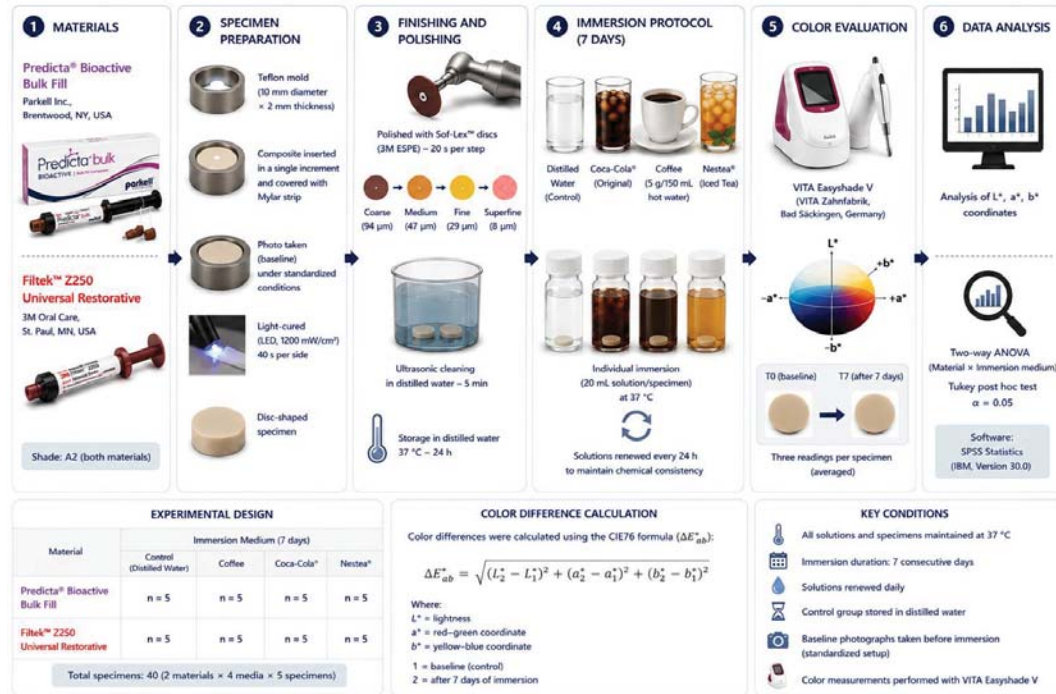
$$\Delta E_{*ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Figure 1. Schematic representation of the CIE L*a*b* color space

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics software (Version 30.0, IBM Corp., Armonk, NY, USA). Descriptive statistics, including mean values and standard deviations, were calculated for all investigated parameters. Data distribution was assessed using the Shapiro–Wilk test.

Differences in the CIELAB color coordinates (L*, a*, and b*) among the experimental groups were analyzed using two-way analysis of variance (Two-Way ANOVA), considering restorative material and immersion medium as independent factors. When significant differences were identified, Tukey's post hoc test was applied for pairwise comparisons. Statistical significance was established at $p < 0.05$.



Scheme I: Experimental workflow of specimen preparation, immersion protocol, color evaluation, and statistical analysis

RESULTS

Color Coordinate Changes Following Beverage Exposure

The mean color coordinate values obtained after seven days of immersion are presented in Table 2. Distinct differences were observed between the tested restorative materials and immersion media, indicating that both factors influenced the optical behavior of the investigated composites.

Table 1. Mean b* values of the investigated materials after seven days of immersion

Material	Control	Coca-Cola	Coffee	Nestea
Predicta Bioactive	23.39 ± 2.18	32.86 ± 0.47	37.59 ± 2.08	33.21 ± 0.90
Filtek Z250	21.63 ± 1.12	21.13 ± 0.64	26.09 ± 0.36	22.95 ± 0.62

Coffee produced the highest increase in the yellow-blue coordinate (b*) for both materials. The greatest mean value was recorded for Predicta Bioactive specimens immersed in coffee (37.59 ± 2.08), followed by Nestea (33.21 ± 0.90) and Coca-Cola (32.86 ± 0.47). In contrast, Filtek Z250 demonstrated substantially lower b* values under identical immersion conditions, with mean values of 26.09 ± 0.36, 22.95 ± 0.62, and 21.13 ± 0.64 for coffee, Nestea, and Coca-Cola, respectively.

Figure 2 illustrates the mean b values recorded after seven days of immersion. The graphical representation highlights the greater susceptibility of Predicta Bioactive to yellow discoloration and confirms the stronger staining effect of coffee compared with Coca-Cola and Nestea.

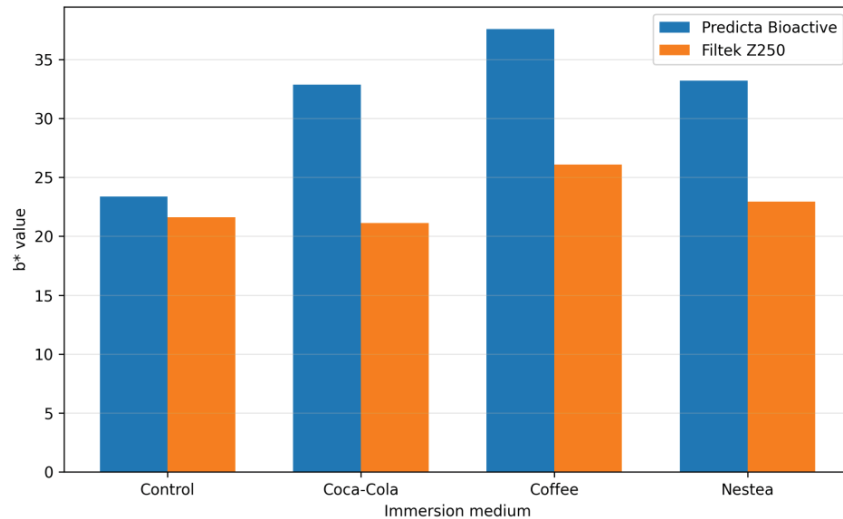


Figure 2. Mean b* values of Predicta Bioactive and Filtek Z250 after seven days of immersion

Compared with the control group, Predicta Bioactive exhibited marked increases in b* values after immersion in all tested beverages, particularly coffee (+14.20 units), followed by Nestea (+9.82 units) and Coca-Cola (+9.47 units). Conversely, Filtek Z250 showed more limited color alterations, with the largest increase observed after coffee exposure (+4.46 units), followed by Nestea (+1.32 units), while Coca-Cola produced virtually no increase in yellowness (-0.50 units relative to control).

Changes in Lightness (L)*

The mean L* values demonstrated a reduction in lightness after immersion, particularly in the coffee groups. Predicta Bioactive specimens showed a decrease from a mean control value of 82.0 to 76.45 following coffee immersion, while Filtek Z250 decreased from 80.59 to 74.90. These findings indicate a darkening effect induced by coffee for both restorative materials. The Coca-Cola and Nestea groups exhibited less pronounced reductions in lightness. For Predicta Bioactive, mean L* values were 82.86 after Coca-Cola exposure and 80.98 after Nestea exposure. Filtek Z250 showed mean values of 79.58 and 80.84 after Coca-Cola and Nestea immersion, respectively.

Changes in the Red-Green Coordinate (a)*

Differences were also observed in the a* coordinate. Predicta Bioactive exhibited a shift toward more positive a* values following immersion, particularly in the coffee group (mean a* = 2.36), indicating increased red chromaticity. The corresponding mean value for Filtek Z250 after coffee immersion was 0.44. Similarly, Coca-Cola and Nestea induced greater variations in a* values for Predicta Bioactive compared with Filtek Z250. These findings suggest that the bioactive material experienced more pronounced chromatic alterations in response to beverage exposure.

Comparative Analysis between Materials

Direct comparison of the two restorative materials revealed consistently higher discoloration-related color coordinate values for Predicta Bioactive. The differences between materials were particularly evident after immersion in coffee and Nestea. Mean b* values were approximately 11.5 units higher for Predicta Bioactive than for Filtek Z250 after coffee immersion and 10.3 units higher after Nestea immersion. Following Coca-Cola exposure, the difference remained substantial at approximately 11.7 units.

Among the tested beverages, coffee exhibited the highest staining potential for both restorative materials. For Predicta Bioactive, coffee induced the most pronounced color

changes, followed by Nestea and Coca-Cola, while the control group showed the lowest degree of discoloration. A similar trend was observed for Filtek Z250, with coffee producing the greatest color alteration, followed by Nestea, whereas the control and Coca-Cola groups demonstrated comparable and substantially lower color changes. These findings indicate that the bioactive composite was more susceptible to beverage-induced color changes than the conventional microhybrid composite under the conditions of the present study.

Visual Assessment

Representative photographs of the specimens after seven days of immersion are presented in Figure 3. Visual examination corroborated the instrumental color measurements, revealing more pronounced discoloration in the coffee-exposed groups and greater color alteration for Predicta Bioactive compared with Filtek Z250. The control specimens maintained the most stable appearance, while Coca-Cola and Nestea produced intermediate staining effects.

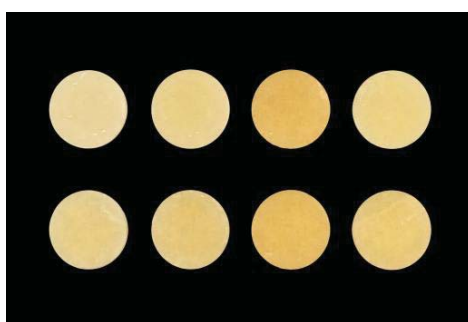


Figure 3. Representative images of the tested specimens after seven days of immersion. The upper row corresponds to Predicta® Bioactive Bulk Fill (Parkell Inc., Brentwood, NY, USA), whereas the lower row corresponds to Filtek™ Z250 Universal Restorative (3M Oral Care, St. Paul, MN, USA). From left to right, the specimens represent the following experimental conditions: control (distilled water), Coca-Cola®, coffee, and Nestea®.

Color Difference Analysis

To provide an overall assessment of discoloration, color differences were estimated using the mean L^* , a^* , and b^* values obtained for each experimental group relative to the corresponding control group. The highest color difference was observed in the coffee groups for both restorative materials. Predicta Bioactive exhibited an estimated ΔE value of 15.77 after coffee immersion, followed by Nestea (10.09) and Coca-Cola (9.55). In contrast, Filtek™ Z250 demonstrated lower color differences, with estimated ΔE values of 7.48, 2.86, and 3.43 following immersion in coffee, Nestea, and Coca-Cola, respectively (Table 3).

The bioactive composite consistently exhibited greater color alteration than the conventional composite under all immersion conditions. The largest difference between materials was observed after coffee exposure, where Predicta Bioactive showed approximately twice the color change recorded for Filtek™ Z250. Similar trends were observed for Coca-Cola and Nestea immersion.

These findings indicate that beverage composition significantly influenced the optical behavior of both restorative materials, with coffee producing the most pronounced discoloration. Furthermore, the bioactive restorative material appeared more susceptible to beverage-induced color changes than the conventional microhybrid composite under the experimental conditions of the present study.

Table 3. Estimated color difference (ΔE^*ab) relative to control specimens after seven days of immersion

Material	Coca-Cola	Coffee	Nestea
Predicta Bioactive	9.55	15.77	10.09
Filtek™ Z250	3.43	7.48	2.86

Figure 4 provides a graphical representation of the estimated ΔE^*ab values obtained after seven days of immersion. The highest color differences were observed in the coffee groups, while Predicta Bioactive consistently showed greater discoloration than Filtek™ Z250 regardless of the immersion medium.

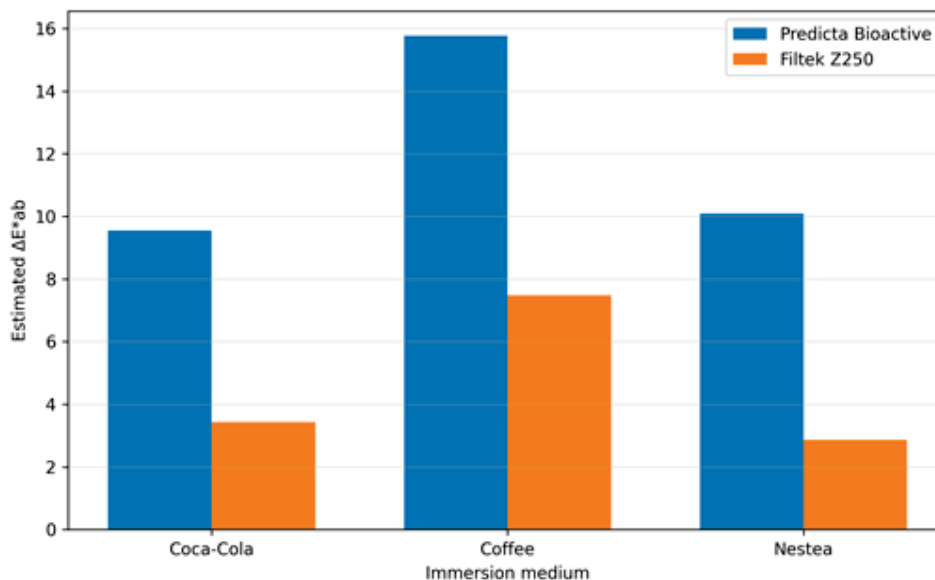


Figure 4. Estimated ΔE^*ab values relative to the control group after seven days of immersion

DISCUSSIONS

The present in vitro study evaluated the esthetic behavior of a bioactive resin composite, Predicta® Bioactive Bulk Fill, compared with a conventional microhybrid composite, Filtek™ Z250 Universal Restorative, after seven days of immersion in commonly consumed beverages. The results showed that both the restorative material and the immersion medium influenced the CIELAB color coordinates and the estimated color difference values. Therefore, the null hypothesis was rejected.

The main finding of this study was that Predicta Bioactive exhibited greater beverage-induced discoloration than Filtek Z250 under all tested conditions. This was particularly evident for the b^* coordinate, which increased markedly in the Predicta groups exposed to coffee, Nestea, and Coca-Cola. Since positive b^* values indicate a shift toward yellow, these findings suggest that the bioactive composite was more susceptible to yellow discoloration than the conventional microhybrid composite. This behavior may be related to the specific composition and functional mechanism of bioactive restorative materials. Bioactive resin-based materials are designed to interact with the surrounding oral environment through ion release, remineralizing activity, and water-mediated processes; however, these same mechanisms may increase water sorption, solubility, and pigment penetration, thereby affecting optical stability. Recent reviews on bioactive dental resins have emphasized that, although these materials have important preventive and remineralizing potential, their long-term physicochemical and clinical stability remains a key challenge[1,3].

Coffee produced the most pronounced color alteration in both restorative materials. This result is consistent with several recent *in vitro* studies reporting coffee as one of the most aggressive staining media for resin composites. Korać et al.[17] found that coffee and tea produced color changes above the clinical acceptability threshold in tested resin composites, while a 2024 study also reported that coffee and red wine caused greater composite discoloration than tea and cola[18]. The high staining potential of coffee may be explained by its yellow-brown chromogens, tannins, and polyphenolic compounds, which may be adsorbed onto the composite surface or absorbed into the resin matrix. In the present study, coffee generated the highest estimated ΔE^*ab values for both Predicta Bioactive and Filtek Z250, confirming its strong chromogenic effect.

The present findings are also in agreement with the study by Uctasli et al.[19], who evaluated the color stability of six resin composites after exposure to commonly consumed beverages and showed that staining susceptibility depends on both the material and the type of beverage. Similarly, recent investigations on resin-based materials exposed to different beverages have shown that coffee and tea-based drinks produce more pronounced discoloration than cola-type beverages[20]. In our study, coffee caused the highest discoloration, while Nestea produced intermediate changes and Coca-Cola showed a lower staining effect, especially for Filtek Z250. This confirms that beverages with both chromogenic compounds and acidic properties may have a stronger impact on color stability than acidic beverages with limited pigment content.

Nestea also produced visible and instrumental color changes, particularly in Predicta Bioactive. Although its staining effect was lower than that of coffee, the increased b^* values observed after Nestea immersion indicate a tendency toward yellow discoloration. This may be related to its tea-derived pigments, colorants, sugars, and acidic components. Previous studies and systematic reviews have shown that tea and tea-based beverages can significantly affect the color stability of tooth-colored restorative materials[17,21]. From this perspective, the findings of the present study support the idea that iced tea beverages should not be considered neutral from an esthetic standpoint, especially in patients with frequent consumption patterns.

Coca-Cola showed different effects depending on the restorative material. In Filtek Z250, Coca-Cola produced minimal changes in b^* values compared with the control group, suggesting relatively good color stability in this acidic but less chromogenic medium. In contrast, Predicta Bioactive showed a marked increase in b^* values after Coca-Cola immersion. This finding suggests that, in the case of the bioactive composite, the acidic environment may have promoted surface or matrix alterations that increased susceptibility to discoloration, even without strong pigment exposure. Acidic beverages may soften the resin matrix, affect the filler-matrix interface, and increase surface roughness, thereby facilitating subsequent optical changes. Recent studies evaluating acidic beverages have reported that these media can alter the microhardness, surface characteristics, and optical properties of resin composite materials[22,23].

The greater discoloration observed for Predicta Bioactive may also be discussed in relation to the balance between bioactivity and esthetic stability. The clinical advantage of bioactive composites is generally associated with ion release, remineralization, and possible pH-buffering effects. However, these properties often require interaction with water and the surrounding environment. Long-term immersion studies on bioactive glass-containing composites have shown that water sorption, solubility, and porosity are relevant parameters when assessing the behavior of bioactive materials over time[14]. Therefore, the higher discoloration found in Predicta Bioactive may reflect a trade-off between functional bioactivity and resistance to staining. This does not diminish the biological potential of

bioactive materials, but it highlights the importance of evaluating their esthetic performance under clinically relevant dietary conditions.

Filtek Z250 showed better color stability than Predicta Bioactive in all immersion media. This may be associated with its conventional resin matrix and zirconia/silica filler system, which may provide a more stable optical structure and lower interaction with aqueous media. Although conventional composites are not bioactive, their long-standing clinical use and optimized filler-matrix structure may contribute to predictable esthetic performance. Recent literature continues to show that resin composite staining is strongly influenced by material composition, resin matrix hydrophilicity, filler loading, particle size, and polishing quality[19,24]. Thus, the lower discoloration of Filtek Z250 in the present study may be attributed to its more stable conventional formulation.

The estimated ΔE_{ab} values confirmed the trends observed in the individual CIELAB coordinates. Predicta Bioactive showed higher estimated color difference values than Filtek Z250 after immersion in all tested beverages. The highest estimated ΔE_{ab} was recorded after coffee immersion, followed by Nestea and Coca-Cola. Although these values were calculated using group mean coordinates rather than individual baseline-post-immersion measurements, they provide an overall indication of the magnitude of color alteration. Importantly, all estimated ΔE^*_{ab} values for Predicta Bioactive were above commonly used clinical acceptability thresholds reported in dental color research, suggesting that the observed changes would likely be clinically relevant. However, this interpretation should be made cautiously because true ΔE values should ideally be calculated for each specimen using paired baseline and final measurements.

From a clinical perspective, the results are relevant because esthetic failure remains an important reason for restoration replacement, even when mechanical integrity is preserved. Patients receiving restorations in visible areas may perceive color mismatch or progressive discoloration as unacceptable. The present findings suggest that dietary habits, particularly frequent coffee or iced tea consumption, should be considered when selecting restorative materials for esthetically demanding regions. Bioactive resin composites may be advantageous in patients with high caries risk because of their potential remineralizing and ion-releasing behavior, but clinicians should be aware that this benefit may not automatically translate into superior color stability. Recent systematic reviews on bioactive resin materials indicate that their clinical superiority over conventional composites is not yet consistently demonstrated, especially when long-term outcomes are considered[15,25].

Therefore, material selection should be individualized. In posterior areas or in patients with increased caries risk, a bioactive restorative material may offer biological advantages. However, in anterior or highly visible areas, where long-term color matching is critical, conventional composites with proven esthetic stability may remain preferable unless further evidence confirms improved optical performance of bioactive alternatives. Preventive dietary counseling is also important. Patients with frequent consumption of coffee, tea-based drinks, or acidic beverages should be informed about the potential risk of restoration discoloration and the need for regular maintenance, polishing, and recall visits.

A strength of the present study is the direct comparison between a commercially available bioactive composite and a well-established conventional microhybrid composite under identical experimental conditions. Another strength is the use of commonly consumed beverages that reflect realistic dietary exposures. The standardized specimen dimensions, shade selection, polishing protocol, immersion temperature, solution renewal, and instrumental color measurement using the CIELAB system also enhance the reproducibility of the study. Moreover, the inclusion of both individual CIELAB coordinates and estimated ΔE^*_{ab} values provides a broader understanding of the optical changes induced by each beverage.

Nevertheless, several limitations should be acknowledged. First, the study was conducted in vitro and cannot fully reproduce the complexity of the oral environment, where saliva, acquired pellicle, oral microbiota, brushing, thermal cycling, pH fluctuations, and masticatory forces influence staining and material degradation. Second, the immersion protocol involved continuous exposure for seven days, which represents an accelerated staining model rather than a direct simulation of normal beverage consumption. Third, the study evaluated only two restorative materials and three beverages, which limits generalizability. Fourth, the study focused primarily on optical parameters; additional surface analyses such as roughness, microhardness, scanning electron microscopy, water sorption, and spectroscopic evaluation would help clarify the mechanisms responsible for discoloration. Finally, the estimated ΔE_{ab} values were calculated from group mean coordinates; future studies should calculate ΔE_{ab} or preferably CIEDE2000 ΔE_{00} for each specimen using paired baseline and post-immersion values.

Future research should include a larger number of bioactive and conventional composites with different resin matrices, filler systems, and ion-releasing technologies. Longer aging protocols, thermocycling, brushing simulation, artificial saliva storage, and pH-cycling models would provide a more clinically relevant assessment of long-term color stability. It would also be valuable to correlate color changes with surface roughness, water sorption, solubility, microhardness, and ion release. Such multimodal analyses could clarify whether increased discoloration is primarily caused by pigment adsorption, resin matrix degradation, filler-matrix breakdown, or bioactive ion-exchange processes. Clinical studies are also needed to determine whether the in vitro staining susceptibility observed in bioactive composites translates into visible discoloration and restoration replacement in patients.

Within the limitations of the present study, the results indicate that Predicta Bioactive was more susceptible to beverage-induced discoloration than Filtek Z250. Coffee was the most aggressive staining medium for both materials, followed by Nestea, while Coca-Cola showed a lower staining effect, particularly for the conventional composite. These findings suggest that bioactivity does not necessarily preserve esthetic stability and that the clinical use of bioactive composites should consider both their biological benefits and their optical behavior under everyday dietary challenges.

CONCLUSIONS

Within the limitations of this in vitro study, both the restorative material and the immersion medium influenced the color stability of the investigated composites. Predicta® Bioactive Bulk Fill demonstrated greater susceptibility to discoloration than Filtek™ Z250 Universal Restorative following exposure to all tested beverages. Among the immersion media, coffee produced the most pronounced color changes, followed by Nestea, whereas Coca-Cola exhibited the lowest staining potential. The bioactive composite consistently showed greater alterations in the evaluated color parameters, indicating reduced resistance to beverage-induced discoloration compared with the conventional microhybrid composite. These findings suggest that the bioactive properties of restorative materials do not necessarily ensure superior esthetic stability. Consequently, both material characteristics and patients' dietary habits should be considered when selecting restorative materials, particularly in esthetically demanding clinical situations. While bioactive composites offer potential therapeutic benefits, clinicians should carefully balance these advantages against their possible susceptibility to discoloration when planning restorations in visible areas.

Conflicts of Interest

The authors declare no conflict of interest.

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