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Effect of sugar and sweetener on the bleachability of coffee and tea-induced stains on composites: an *in vitro* experimental study

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ABSTRACT

Objectives: This *in vitro* study evaluated the effects of various sugary and non-sugary beverages on the color change of a dental composite and the subsequent bleaching efficacy.

Methods: Forty-nine disc-shaped composite samples (Neo Spectra ST, Dentsply Sirona) were split into seven groups at random ($n = 7$). Distilled water was used to hydrate each sample for 24 hours at 37°C. After 24 hours, the first color measurements (T0) were made by using a clinical spectrophotometer (VITA Easyshade Compact; VITA Zahnfabrik). Color measurements were repeated after 7 days (T1) and 14 days (T2) of immersion in distilled water (control), tea, coffee, sugary tea, sugary coffee, tea with sweetener added, and coffee with sweetener added. After staining for 2 weeks, the specimens were bleached for 6 hours a day for a week using 16% carbamide peroxide (Opalescence Ultradent Products). Color measurements were taken again after bleaching (T3). Using CIEDE2000, color differences (ΔE) were computed. Analysis of variance (ANOVA) and repeated measures ANOVA with a Tukey *post hoc* test were used to evaluate the data.

Results: After 1 week, coffee-containing solutions produced significantly greater discoloration than the control ($p < 0.001$). By 2 weeks, tea groups exhibited similar discoloration to coffee groups ($p < 0.001$). The addition of sugar or sweetener had no significant effect ($p > 0.05$). Post-bleaching, coffee groups showed lower Whiteness Index values than the control, without statistical significance ($p > 0.05$).

Conclusions: Coffee and tea markedly stain resin composites, with discoloration persisting post-bleaching, while sugar or sweetener additions exert no significant effect.

Keywords: Color; Composite resins; Tooth bleaching; Sugars

INTRODUCTION

Aesthetics plays a vital role for patients undergoing dental procedures. Resin composite is frequently chosen as a direct restorative material due to its versatility. Achieving an initial and long-term color match with surrounding teeth is crucial for its success. However, continuous exposure of resin composite to beverages can lead to

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discoloration over time [1]. Intraoral resin composite restorations can undergo discoloration due to either intrinsic or extrinsic factors. Intrinsic factors are linked to the resin composite's composition, such as the type of photo-initiator and resin matrix used. Conversely, extrinsic factors involve the absorption or adsorption of stains from external sources, which are largely influenced by an individual's dietary habits. Common beverages like tea and coffee, for instance, are known to stain both natural teeth and tooth-colored restorations, presenting aesthetic challenges and frustrations for patients [2,3].

Bleaching offers a minimally invasive method to whiten teeth affected by stains, whether they originate from external sources or are embedded within the tooth structure. Techniques for bleaching can be categorized based on whether they target vital or non-vital teeth, as well as whether the procedure is conducted professionally in a dental office or includes a self-administered component for home use [4–6]. These agents, functioning through comparable mechanisms, interact with and dismantle the organic pigment molecules accountable for tooth discoloration [7]. Hydrogen peroxide and carbamide peroxide are the predominant active ingredients in bleaching products. These substances vary in concentration based on the type of bleaching agent used. Home bleaching kits are applied over extended periods with lower concentrations of active ingredients, whereas office-based bleaching procedures involve shorter application times with higher concentrations of active substances [8].

Extraoral spectrophotometers remain the gold standard due to their precision and ability to provide consistent measurements in controlled environments. Conversely, intraoral spectrophotometers offer practical advantages by allowing for on-site color determination, which is particularly valuable during dental procedures [9]. In the context of color measurement, the CIEDE2000 formula provides a more accurate reflection of human color perception compared to older methods such as the original CIELAB system. The perceptibility threshold of ΔE00 = 0.8 indicates the smallest color difference that an average observer can detect, while the acceptability threshold of ΔE00 = 1.8 suggests the limit beyond which color differences are considered unacceptable or noticeable [10].

Stevia has been used as a natural sweetener in many countries for years due to its properties, such as being good for various diseases such as diabetes, being calorie-free, non-toxic, and not participating in browning reactions during food processing. In addition to its features, such as being 300 times sweeter than sucrose, having high heat and pH stability, baking and oven stability, being soluble in alcohol, and not leaving a metallic taste in the mouth, its most important feature is that it can be produced naturally [11].

Although there are many studies in the literature on coloring solutions, there is no study on the addition of sugar or sweetener to these beverages. Considering that tea and coffee in Türkiye are typically consumed with added sugar, this study included sugar and sweeteners in the colored beverages. This *in vitro* study evaluated how these solutions, both with and without sugar or sweetener, impact coloration and the subsequent success of bleaching. The study hypotheses are as follows: (i) Storage in different beverages would not affect the color stability of composite resins. (ii) Adding sugar or a sweetener to beverages would not have any effect on the color change. (iii) The bleaching protocol would not affect the Whiteness Index values of all groups.

METHODS

Sample preparation

An a priori power analysis was conducted using G*Power software (version 3.1.9.6; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) to determine the minimum sample size required to detect meaningful differences among the experimental groups. The power calculation was based on the main effect of additive (none, sugar, sweetener) in a 2 × 3 two-way analysis of variance (ANOVA) design (beverage × additive), with numerator degrees of freedom = 2. A total of 49 specimens were included; 42 specimens fulfilled the requirements of the 2 × 3 factorial design, while the remaining seven specimens formed an independent control group. A medium-to-large effect size was assumed (f = 0.50), together with a significance level of α = 0.05 and a target statistical power of 0.80. Under these assumptions, the required total sample size was 42 specimens (seven per

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group), yielding an actual power of 0.80. According to Cohen's classification, the assumed effect size (f = 0.50) corresponds to a medium-to-large effect and was considered appropriate for the present controlled *in vitro* design. Forty-nine composite specimens (Neo Spectra ST; Dentsply Sirona, Konstanz, Germany) were prepared in a Teflon mold (5 mm in diameter and 2 mm in thickness). After applying the composite resin, a Mylar strip was placed and pressed with a glass slide to obtain a flat surface. The specimens were cured for 20 seconds using an LED light-curing unit (VALO; Ultradent Products Inc., South Jordan, UT, USA). The specimens were removed from the mold and assessed visually for voids and structural defects. Defected specimens were excluded from the study. In the next step, the specimen surfaces were polished with Sof-Lex discs (3M ESPE, St. Paul, MN, USA) for 15 seconds. Specimens were randomly divided into seven groups (n = 7). Beverages used in this experiment were the control group (distilled water), instant tea, tea + sugar added, tea + sweetener added, instant coffee, coffee + sugar added, and coffee + sweetener added.

1) Control group: In this group, the composite specimens were kept in distilled water only.
2) Tea group: The tea solution was prepared by means of the following procedure. Two prefabricated doses (2 × 2 g) of tea (Yellow Label Tea; Lipton, Rize, Türkiye) were immersed in 200 mL of boiling water at 100°C for 1 minute. After removing the tea waste, the final solution volume was determined to be 200 mL.
3) Coffee group: The coffee solution was prepared by first pouring 6 g of Nescafé Classic ground coffee powder (Nestlé S.A., Vevey, Switzerland) into a coffee filter. Then, 200 mL of water at 100°C was added. The solution obtained was subsequently subjected to a secondary filtration process, resulting in the attainment of a final volume of 200 mL.
4) Tea + 5 g sugar added group: The tea solution was prepared as described above. After this step, 5 g of sugar was added and mixed until dissolved.
5) Coffee + 5 g sugar added group: The coffee solution was prepared as described above. After this step, 5 g of sugar was added and mixed until dissolved.
6) Tea + sweetener added group: The tea solution was prepared as described above. After this step, two units (0.1 g) of sweetener (Splenda Stevia; Heartland Food Products Group, Indianapolis, IN, USA) were added and mixed until dissolved.
7) Coffee + sweetener added group: The coffee solution was prepared as described above. After this step, two units (0.1 g) of sweetener (Splenda Stevia) was added and mixed until dissolved.

Color measurement

All discoloration solutions were renewed daily, and the specimens were rinsed with distilled water for 10 seconds before measurements. The specimens were stored in these staining solutions at 37°C ± 2°C in a dark environment. The color coordinates of specimens were recorded after 24 hours (T0), 1 week (T1), and 2 weeks (T2) of immersion.

All color measurements were performed by using a clinical spectrophotometer (VITA Easyshade Compact; VITA Zahnfabrik, Bad Säckingen, Germany) according to the CIEDE2000 color coordinates. Prior to each measurement, the spectrophotometer was calibrated following the manufacturer's guidelines [12]. To determine the color differences between groups, the ΔE00 values were calculated by using the following formula [5]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L}{K_L S_L}\right)^2 + \left(\frac{\Delta C}{K_C S_C}\right)^2 + \left(\frac{\Delta H}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C}{K_C S_C}\right)\left(\frac{\Delta H}{K_H S_H}\right)},$$

With the set of L*, a*, b* values taken with respect to the white background. For this study, each K_L, K_C, and K_H was set to 1.0. It is posited that variations in brightness, chroma, and hue are represented by variables ΔL, ΔC, and ΔH. While S_L, S_C, and S_H are averaging variables for lightness, chroma, and hue, K_L, K_C, and K_H are weighted factors. R_T is a general correction factor that takes into account variations in chroma and hue [13]. The clinically 50:50% acceptable color change threshold level was determined as ΔE00 = 1.8 (10).

Home bleaching procedure

The home bleaching technique, 16% carbamide peroxide (Opalescence 16%; Ultradent Products Inc.) was placed on each sample surface, using a dispenser tip, forming a layer that was up to 1 mm thick. The bleach-

ing agent was left in contact with each tooth sample for a period of 6 hours daily for 1 week and was subsequently removed using a cotton pellet and rinsing [14]. During bleaching intervals, specimens were maintained in the incubator at 37°C. This procedure was repeated on a daily basis for a total of 1 week. After bleaching, color measurements were taken again (T3).

Statistical analysis

Power analysis was conducted using G*Power software (version 3.1.9.6). The analysis of the data was conducted using IBM SPSS ver. 23 (IBM Corp, Armonk, NY, USA). Following a thorough evaluation, it was determined that the distributions exhibited characteristics consistent with normality, as evidenced by the Kolmogorov-Smirnov test. A three-way and two-way ANOVA test was applied in order to ascertain whether there were any significant differences among the groups. The Tukey test was employed as a *post hoc* analysis to evaluate the pairwise comparisons. The significance level was predetermined at $p < 0.05$.

RESULTS

All solutions containing coffee showed significantly more coloration than the control group after 1 week of immersion ($p < 0.001$, $\eta p^2 = 0.72$) (Figure 1). Adding sugar or a sweetener to the tested beverages had no significant effect on coloration ($p > 0.05$). Color change became evident, especially in the tea groups, in the 2nd week (Figure 2).

The results demonstrated that both coffee and tea caused a darkening effect on the samples over time, as indicated by the decrease in L^* values in Figure 3. The bleaching treatment was effective in increasing the L^* values, indicating a lightening effect. The control group showed a consistent increase in L^* values after bleaching, indicating that the treatment works well in the absence of staining agents. Coffee appeared to have a more pronounced darkening effect compared to tea, as evidenced by the larger decrease in L^* values over time.

For a^* values coffee caused a significant shift towards red on the a^* axis over time in Figure 4, while tea had a milder effect. The bleaching treatment was effective in reducing the red shift, bringing the a^* values closer to the baseline, especially in the tea group. The control group showed minimal changes in the a^* values throughout the experiment, indicating stability in the red-green axis in the absence of staining agents.

When the results were examined in Figure 5, it was seen that coffee caused a significant yellowish tint on the samples over time, as indicated by the increase in b^* values. The bleaching treatment was effective in reducing the yellowish tint, bringing the b^* values closer to the baseline. The tea group showed a unique behavior at the 2-week mark, where the b^* values decreased signifi-

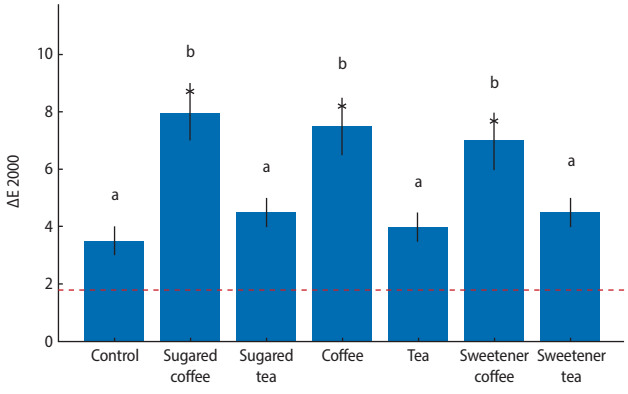


Figure 1. Mean color changes (ΔE_{00}) of composite samples after 1 week of immersion in different beverages. Different letters indicate statistically significant differences among groups. The red dashed line ($\Delta E_{00} = 1.8$) represents the clinical acceptability threshold for perceptible color change.

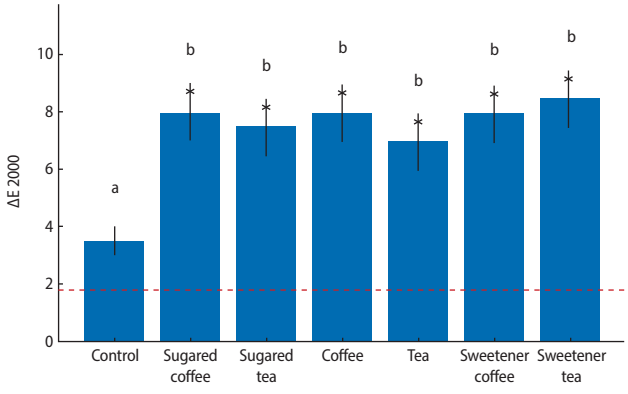


Figure 2. Mean color changes (ΔE_{00}) of composite samples after 2 weeks of immersion in different beverages. Different letters indicate statistically significant differences among groups. The red dashed line ($\Delta E_{00} = 1.8$) denotes the clinical acceptability threshold for perceptible color difference.

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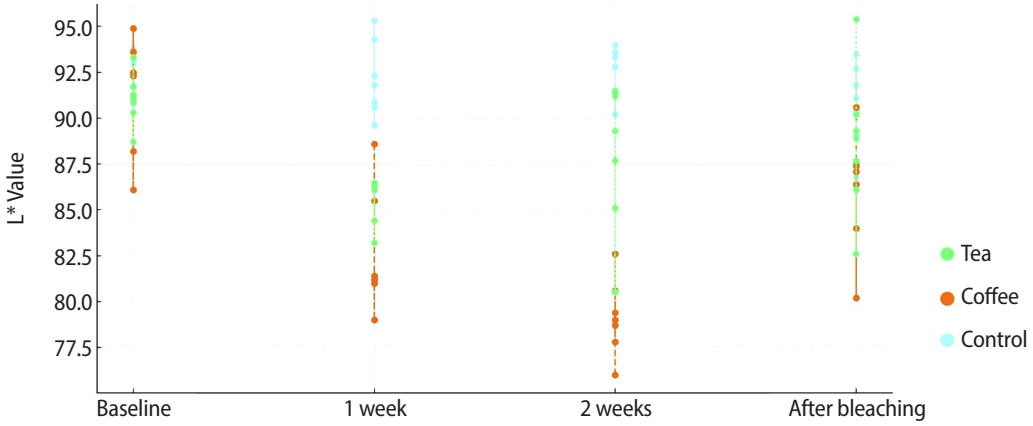


Figure 3. Changes in L* values of composite samples at baseline, after 1 week, 2 weeks of staining, and following bleaching for tea, coffee, and control groups. A decrease in L* indicates darkening, while an increase reflects lightening of the specimens.

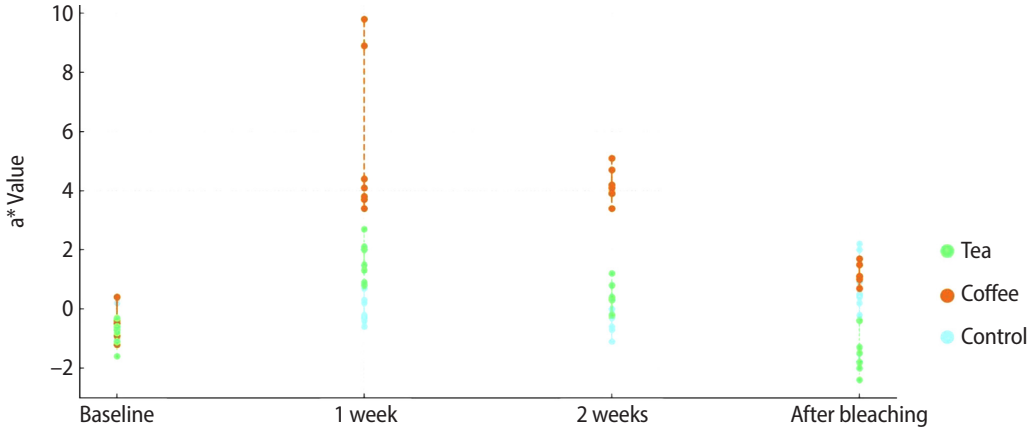


Figure 4. Changes in a* values of composite samples at baseline, after 1 week, 2 weeks of staining, and following bleaching for tea, coffee, and control groups. An increase in a* indicates a shift toward red, while a decrease represents a shift toward green.

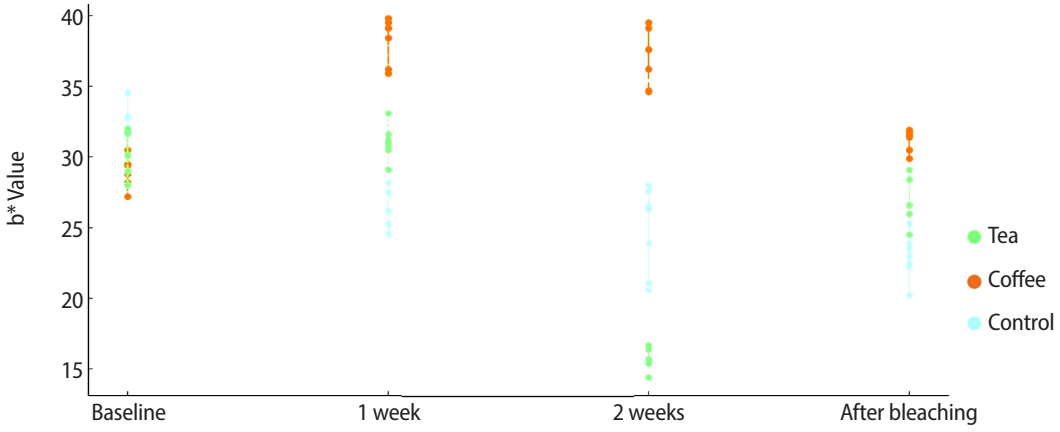


Figure 5. Changes in b* values of composite samples at baseline, after 1 week, 2 weeks of staining, and following bleaching for tea, coffee, and control groups. An increase in b* indicates a shift toward yellow, while a decrease represents a reduction in yellow hue after bleaching.

cantly, indicating a reduction in the yellowish tint. This is contrary to the behavior observed in the coffee group and suggests that tea might have a different interaction with the sample material over extended exposure. This could be due to various factors, such as chemical interactions between tea components and the sample material that inhibit yellowing over time.

The heatmap visually represents the overall color changes for each group over time. Coffee had a pronounced yellowing effect, while tea caused a milder yellowing effect with an unusual reduction at the 2-week mark (Figure 6). Bleaching effectively lightened the color across all groups, with the tea group returning closer to baseline after bleaching. The control group remained relatively stable with a slight lightening effect over time. This visualization highlights the impact of different staining agents and bleaching treatments on the overall color of the samples.

When the Whiteness Index values were examined after bleaching in Figure 7, it was determined that the coffee groups showed statistically lower values than the control group. The whiteness values of the tea groups

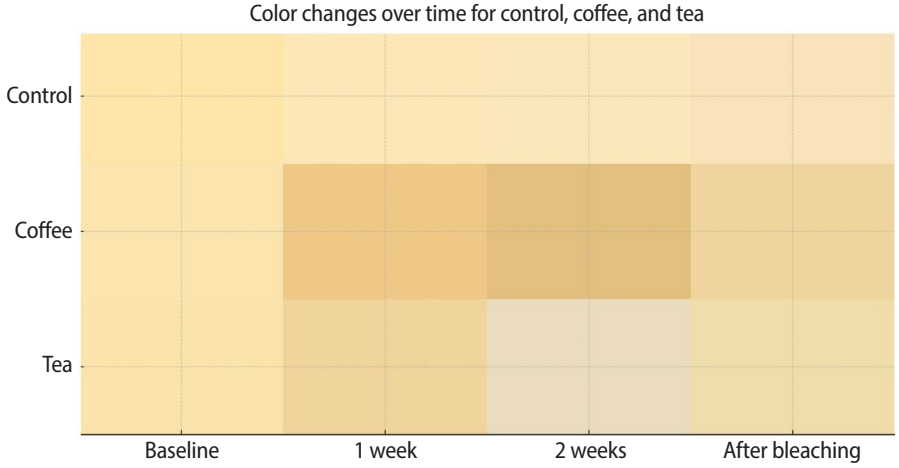


Figure 6. The visualization of the color changes over time for control, coffee, and tea samples. Each cell represents the average color at each time point for each group, converted from Lab* to RGB values.

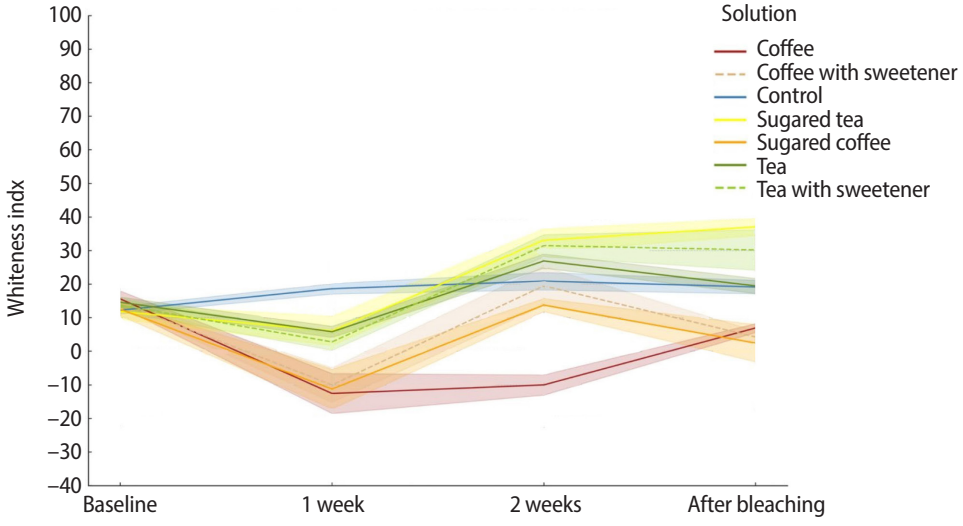


Figure 7. Whiteness index values with 95% confidence intervals.

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were similar and partially higher than those of the control group. Tea groups showed higher values than the coffee groups.

DISCUSSION

The present study investigated the staining susceptibility of dental composites to commonly consumed beverages and their response to bleaching treatment, with particular attention to the novel aspect of sugar and sweetener additives. The findings demonstrate that both coffee and tea significantly compromise the color stability of composite resins, with staining effects persisting even after bleaching procedures, thus leading to the rejection of the first hypothesis.

The significant discoloration observed in all beverage groups compared to the control can be attributed to the complex interaction between chromogenic compounds and the composite matrix. Coffee-containing solutions demonstrated more pronounced staining effects after 1 week of immersion ($p < 0.001$), which aligns with previous research indicating that coffee contains higher concentrations of tannins and chromogenic compounds compared to tea [15]. The polyphenolic compounds in these beverages can penetrate the resin matrix through micro-porosities and form chemical bonds with the polymer chains, resulting in staining [16].

The staining durations of 1 and 2 weeks were selected to represent both short-term and extended exposure models, enabling the evaluation of progressive discoloration patterns under conditions that approximate daily beverage consumption. It has been reported that 24 hours of *in vitro* immersion corresponds to approximately 1 month of *in vivo* aging, supporting the assumption that the 1-week immersion period used in the present study roughly simulates 6–8 months of clinical beverage exposure [17], whereas extending the exposure to 2 weeks provides a more intensified model that mimics long-term consumption habits [1,15,16]. This design allows assessment of both the initial discoloration potential and the saturation stage of staining over time. Therefore, the 1-week duration was chosen to observe early color changes, while the 2-week duration was included to investigate whether color stabilization or further pigment accumulation would occur with prolonged exposure. Similarly, a 1-week bleaching period using 16% carbamide peroxide for 6 hours daily reflects a commonly recommended home bleaching protocol, which has been reported to achieve effective color recovery without compromising composite integrity [8,14]. Therefore, the chosen durations were designed to balance experimental efficiency with clinical relevance, allowing reliable comparison of staining and bleaching behavior within a controlled timeframe.

The differential staining patterns observed between coffee and tea groups reflect their distinct chemical compositions. Coffee's more immediate and pronounced effect on the L^* values (lightness) indicates greater penetration of dark-colored compounds, while the unique behavior of tea at the 2-week mark—where b^* values decreased significantly—suggests a complex interaction possibly involving tannin precipitation over extended exposure periods. This finding warrants further investigation using spectroscopic analysis to elucidate the underlying chemical mechanisms.

A key finding of this study is that the addition of sugar or stevia-based sweetener did not significantly affect the staining potential of either coffee or tea ($p > 0.05$), leading to acceptance of our second hypothesis. This result is particularly relevant given the cultural context where these beverages are commonly consumed with additives. Several factors may explain this finding: The sugar concentration used (5 g per 200 mL) may not be sufficient to alter the physical properties of the staining solutions significantly, neither sucrose nor stevia appears to interfere with the chromogenic compounds responsible for staining, the molecular size of sugar and stevia compounds may not significantly alter the diffusion pathways of staining agents into the composite matrix. This finding has important clinical implications, suggesting that patients need not avoid sweeteners in their beverages specifically to prevent composite staining, though the beverages themselves remain problematic.

The bleaching protocol using 16% carbamide peroxide demonstrated variable success across different staining agents. While the treatment effectively increased L^* values (lightness) in all groups, indicating successful removal of chromogenic compounds, the coffee groups showed persistently lower Whiteness Index values compared to controls after bleaching ($p < 0.05$), leading to

rejection of our third hypothesis.

Coffee-induced stains may penetrate deeper into the composite matrix or form stronger chemical bonds that are more resistant to oxidative bleaching agents or the 16% carbamide peroxide concentration, while appropriate for home bleaching protocols, may be insufficient for complete removal of deeply embedded stains. Higher concentrations or alternative bleaching agents might yield better results, though this requires investigation of potential adverse effects on composite properties.

The slight decrease in L^* values observed in the control group after bleaching may be attributed to surface alterations induced by the bleaching agent rather than pigment removal. Although no staining agents were present, exposure to carbamide peroxide can cause superficial dehydration or changes in surface roughness and refractive index, which can temporarily reduce brightness perception [4,5]. In addition, microscopic surface irregularities formed by oxidative reactions might scatter light differently, leading to a minor reduction in measured L^* values despite the absence of external staining. Similar findings have been reported by Rodrigues *et al.* [6] and Karataş *et al.* [8], who noted that bleaching agents may induce subtle optical or microstructural changes even in unstained composite materials.

The staining and bleaching behaviors of resin composites are strongly influenced by their intrinsic material characteristics, particularly the resin matrix composition, filler type, and filler load. Composites with a higher proportion of hydrophilic monomers such as triethylene glycol dimethacrylate exhibit greater water sorption and pigment uptake compared to those with more hydrophobic matrices like bisphenol A-glycidyl methacrylate or urethane dimethacrylate [18,19]. Increased filler content and smaller particle size improve surface smoothness and reduce microvoids, thereby minimizing stain penetration and facilitating more efficient bleaching [9]. Conversely, composites with lower filler loading or irregular filler distribution tend to have higher surface roughness, promoting adsorption of chromogenic molecules and limiting the penetration of bleaching agents [8]. Overall, materials with dense filler packing, reduced water sorption, and a highly cross-linked, hydrophobic resin matrix generally demonstrate superior stain resistance and more predictable bleaching outcomes.

The present study employed Neo Spectra ST (Dentsply Sirona), a nanohybrid composite resin incorporating SphereTEC filler technology, which is designed to provide improved handling characteristics, high filler loading, and enhanced optical blending with natural dentition. According to previous investigations, this material demonstrates satisfactory clinical and esthetic performance; however, some studies have indicated that its color stability and surface properties may vary depending on the staining medium and finishing protocols used. For instance, a recent *in vitro* study comparing Neo Spectra ST high viscosity with other universal composites reported significantly higher ΔE values after immersion in coffee and tea solutions, suggesting a moderate susceptibility to extrinsic discoloration [20]. Similarly, Shah *et al.* [21] observed that Neo Spectra ST exhibited slightly lower microhardness values than other nanohybrid composites, which may contribute to its surface roughness and potential for stain accumulation. Nevertheless, long-term clinical studies have shown that Neo Spectra ST provides acceptable overall performance, with only minor increases in surface wear or discoloration over time [22,23].

Given this evidence, the use of Neo Spectra ST in the current study is justified, as it represents a widely used, clinically relevant material with well-documented mechanical and optical characteristics. The absence of comparable studies examining the influence of sweetener or sugar additives on the staining behavior of this composite highlights the novelty of the present research. Therefore, while findings from other materials may not be directly extrapolated, the results obtained here contribute valuable insight into the color stability of Neo Spectra ST under conditions simulating common beverage consumption habits. Future research comparing different composite systems and sweetener types would further clarify whether these findings are material-specific or represent a broader trend among nanohybrid resin composites.

The persistent staining observed even after bleaching treatment has several important clinical implications: Patients should be informed that dietary habits significantly impact the longevity of composite restorations' aesthetic properties, and that bleaching may not com-

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pletely restore original coloration. In patients with high consumption of staining beverages, alternative restorative materials with superior stain resistance or more frequent replacement schedules should be considered. While sugar and sweetener additives do not increase staining risk, the base beverages themselves remain problematic. Patients might benefit from strategies such as using straws, limiting contact time, or immediately rinsing after consumption. The findings suggest that preventive measures are more effective than corrective bleaching, emphasizing the importance of patient education and dietary counseling.

Several limitations must be acknowledged when interpreting these findings: The study examined only one composite system. Different resin matrices, filler compositions, and surface treatments may respond differently to staining and bleaching protocols. Future studies should investigate multiple composite systems to establish broader clinical applicability. The *in vitro* design, while providing controlled conditions, cannot replicate the complex oral environment. Factors such as saliva flow, pH fluctuations, masticatory forces, and oral hygiene practices significantly influence staining patterns in clinical settings. The daily renewal of staining solutions may not accurately represent typical beverage consumption patterns.

Future studies—particularly *in vivo* and in situ investigations—are necessary to confirm these findings under clinically relevant conditions.

CONCLUSIONS

This study demonstrates that coffee and tea consumption significantly compromises the color stability of dental composites, with coffee showing more pronounced and persistent staining effects. Importantly, the addition of sugar or stevia-based sweeteners does not exacerbate staining, providing valuable information for patient counseling. However, the limited efficacy of bleaching treatments, particularly for coffee stains, emphasizes the importance of preventive strategies over corrective interventions. These findings should inform clinical decision-making regarding material selection, patient counseling, and maintenance protocols for composite restorations in patients with high consumption of chromogenic beverages.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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