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Effects of Coffee Prepared with Different Milk Types on the Color Stability and Surface Roughness of Resin-Based Composites

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Abstract

Objective

This study aimed to evaluate the effects of black coffee and coffee prepared with different milk types on the color stability and surface roughness of resin-based composites.

Materials and Methods

Eighty disc-shaped specimens were prepared from a nanohybrid composite (G-ænial A'CHORD) and a single-shade universal composite (Omnichroma). Specimens were immersed in distilled water, black coffee, bovine milk coffee, oat milk coffee, or almond milk coffee for 12 days to simulate long-term beverage exposure. Color change (ΔE_{00}) was measured using a digital spectrophotometer according to the CIEDE2000 system, while surface roughness (Ra) was evaluated using a contact profilometer. Data were analyzed using Two-Way ANOVA, Welch ANOVA, Kruskal–Wallis, and appropriate post-hoc tests ($p < 0.05$).

Results

Beverage type significantly affected color change values in both materials ($p < 0.001$). Omnichroma exhibited significantly higher ΔE_{00} values than G-ænial A'CHORD, particularly in the black coffee and oat milk coffee groups. In both composites, the lowest color change among coffee-containing groups was observed in the bovine milk coffee group. Surface roughness values remained below the clinically acceptable threshold in all groups; however, only the Omnichroma black coffee group showed a significant increase ($p = 0.024$). No significant correlation was found between color change and surface roughness ($p > 0.05$).

Conclusion

Different milk types influenced the staining behavior of resin-based composites. While bovine milk reduced coffee-induced discoloration, oat milk was associated with greater color change, particularly in the single-shade universal composite material.

1. Introduction

Resin-based composites are widely used in restorative dentistry because they combine satisfactory mechanical performance with excellent esthetic outcomes (1). However, the long-term clinical success of these materials depends on their surface integrity and optical stability under thermal and chemical stresses in the oral environment. Chromogenic beverages, among the extrinsic factors affecting the

aesthetic performance of restorative materials, have been reported to negatively affect the color stability and surface properties of composite restorations (2, 3).

Coffee is among the beverages that cause the most clinically significant discoloration due to the penetration of low-polarity coloring agents into the resin matrix (4, 5). The CIEDE2000 system, used to evaluate color change (ΔE_{00}), uses 0.8 as the visual perception threshold and 1.8 as the clinically acceptable limit (6).

Surface roughness (Ra) is critical for the aesthetic success and biological performance of dental restorations. Increased surface irregularity can lead to discoloration and aesthetic loss by increasing plaque retention, bacterial adhesion, and the retention of chromogenic agents on the surface (1). The literature reports that for restorative surfaces to be considered resistant to bacterial adhesion and clinically acceptable in terms of smoothness, the average Ra value should be below 0.2 μm (7).

With changes in dietary habits in recent years, the consumption of plant-based milk alternatives is rapidly increasing globally for both health and environmental reasons (8, 9). Plant-based milk alternatives differ significantly from bovine milk in terms of protein, fat, and carbohydrate composition (10, 11). Bovine milk has a richer nutritional profile, particularly in terms of protein and fat content, whereas plant-based alternatives, including almond and oat milk, generally contain less protein and more carbohydrates (10).

It has been reported that plant-based milk alternatives may have different effects on tooth enamel erosion and caries formation, depending on their buffering capacities and compositional properties. In contrast, it is thought that bovine milk, thanks to its calcium, phosphate, and casein content, may have a more protective effect against acid attacks by remineralizing tooth enamel (12, 13).

While the staining potential of coffee is well established, current data on the effects of coffee prepared with bovine milk and plant-based milk alternatives (oat and almond) on resin-based composites are limited. In this study, the effects of black coffee and coffee solutions with added bovine, oat, and almond milk on the color stability and Ra of resin-based composites were comparatively evaluated. Therefore, evaluating the effects of coffee prepared with different types of milk on restorative materials is important for predicting the long-term clinical performance of aesthetic restorations.

The null hypothesis of the study is that coffee solutions prepared with different types of milk have no significant effect on the color stability and Ra of composite resins, and there are no differences between the materials.

2. Materials and Methods

2.1. Sample Size Calculation

The minimum sample size was determined using G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany). A significance level of α = 0.05 and a statistical power of 1 − β = 0.90 were set for all analyses. Based on a previous study, an effect size of f = 0.53 for ΔE with 10 groups required a minimum of 8 specimens per group (total n = 80, actual power = 0.903), and an effect size of dz = 0.44 for Ra required a minimum of 6 paired samples per group (total n = 59, actual power = 0.901). To ensure robust and reliable results, 8 specimens were used per group for both analyses (14).

2.2. Experimental design

In this in vitro study, the effects of distilled water, black coffee, bovine milk coffee, oat milk coffee, and almond milk coffee solutions on the color stability and surface roughness (Ra) of two different resin-based composite materials were evaluated using a total of 80 disc-shaped specimens. The overall study design and experimental workflow are presented in Fig. 1.

2.3. Materials

In this study, two different resin-based composite materials, G-ænial A'CHORD A2 (GC Corporation, Tokyo, Japan) and Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan) (Table 1), were used, along with Torku® milk (Konya Food and Agriculture University Food and Agriculture Inc., Konya, Turkey), Alpro® Oat Milk, and Alpro® Almond Milk (Alpro, Belgium).

Table 1
Characteristics of the resin-based composite materials used in the study.

Material	Main components (resin matrix/filler)	Manufacturer	Filler % (wt%/vol%)	Lot
G-ænial A'CHORD (A1)	Nanohybrid BisMEPP, TEGDMA, UDMA 300 nm barium glass filler, 16 nm fumed silica, organic filler (300 nm barium glass; 16 nm fumed slica)	GC Corporation, Tokyo, Japan	82% -65%	220620B
Omnichroma	Nanofill UDMA, TEGDMA, Uniform sized supra-nano spherical filler (260 nm spherical SiO2-ZrO2) and composite filler	Tokuyama Dental Corporation, Tokyo, Japan	79% – 68%	092E82

2.4. Specimen Preparation

Standard disc-shaped specimens were prepared from both composite materials, using Teflon molds with an 8 mm diameter and 2 mm thickness. Eight specimens were prepared for each experimental group, yielding a total of 80. After placing the composite materials in the molds, Mylar strips and 1 mm thick

glass slides were placed on them to ensure surface smoothness, and then polymerized for 20 seconds using an O-Star LED light device (Guilin Woodpecker Medical Instrument Co., Guangxi, China) with a light intensity of 1000 mW/cm². The surfaces to be analyzed were pre-marked to ensure that measurements could be repeated from the same surface in each specimen. All specimens were polished by a single researcher using a four-stage aluminum oxide polishing system (TOR VM discs, Russia) under continuous water cooling and low pressure, with the polishing discs replaced every 5 specimens. To standardize initial conditions, all specimens were immersed in distilled water at 37°C for 24 hours before the experimental procedures.

2.5. Grouping and Immersion Procedure

The prepared samples were divided into five groups according to the environment in which they would be kept: distilled water, black coffee, bovine milk coffee, oat milk coffee, and almond milk coffee. Eight samples were included in each group for both composite materials. The coffee solution was prepared by completely dissolving 2 g of instant coffee (Nescafé Classic, Nestlé, Switzerland) in 100 mL of boiling water to ensure standardization. In the milk-containing groups, the coffee-milk mixture ratio was applied as 5 mL of milk added to 100 mL of coffee solution (15). Bovine milk, oat milk, and almond milk were used to prepare coffee solutions at the same volumetric ratio, and the respective milks were added to the coffee solutions at 5% (v/v). All samples were kept in the respective solutions for 12 days (3). This period was selected to simulate approximately 1 year of beverage exposure, as per previously reported accelerated aging protocols. During storage, the solutions were replaced daily, and the samples were stored at 37°C.

2.6. Color Change Measurement (ΔE_{00})

Color evaluations were performed using a digital spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Germany). To ensure measurement accuracy, the instrument was calibrated before each measurement according to the manufacturer's instructions. All measurements were taken on a white background under standard D65 illumination, with the measuring probe positioned 90° perpendicular to the sample surface. Initial color measurements (T_0) were taken three times for each sample after immersion in distilled water for 24 hours, and the average values were recorded. At the end of the twelve-day immersion period (T_1), the samples were removed from the solutions, washed with distilled water, dried, and re-measured following the same protocol. Color change was calculated as ΔE_{00} using the CIEDE2000 system (Eq. 1). In this system, the L* value represents the lightness-darkness axis, the a* value represents the red-green axis, and the b* value represents the yellow-blue axis. The clinically acceptable threshold was set at $\Delta E_{00} = 1.8$ (6).

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{\frac{1}{2}}$$

Equation 1. CIEDE2000 color difference formula.

2.7. Surface Roughness (Ra) Measurement

Ra measurements were performed using a contact profilometer (Taylor Hobson Surtronic S-128, AMETEK, United Kingdom) 24 hours after sample preparation and after the completion of the 12-day immersion period. Measurements were recorded in Ra (μm). The instrument settings were standardized with a cut-off value of 0.25 mm and a measurement length of 1.25 mm. Measurements were taken from three different points on the surface of each sample, and the arithmetic mean of these measurements was accepted as the Ra value of the relevant sample.

3. Statistical Analysis

Statistical analyses were performed using SPSS v27.0 software (IBM Corp., Armonk, NY, USA). Data normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene tests, respectively.

Color change (ΔE_{00}) data were analyzed using Two-Way ANOVA to evaluate the effects of material type, solution type, and their interaction. Differences among solution groups were assessed using Welch ANOVA due to the violation of the homogeneity of variance assumption, and multiple comparisons were performed using Tamhane's T2 post-hoc test.

Since the surface roughness data for the composite resins did not follow a normal distribution, nonparametric tests were used. Initial and final surface roughness values within each group were compared using the Wilcoxon signed-rank test. The effects of different solutions on surface roughness change (ΔRa) were evaluated using the Kruskal–Wallis H test, followed by Dunn–Bonferroni post-hoc comparisons. The effect of material type on ΔRa within different solution groups was analyzed using the Mann–Whitney U test.

The presence and direction of the relationship between ΔRa and ΔE_{00} values were evaluated using Spearman's correlation analysis. Statistical significance was set at $p < 0.05$ for all analyses.

4. Results

4.1. Color Change ΔE_{00} Results

Descriptive statistics for color change (ΔE_{00}) values are presented in Table 2.

Table 2
Mean, standard deviation, and 95% confidence interval data for color change (ΔE_{00}) of two different restorative materials immersed in coffee solutions containing different milk additives.

Materials	Immersion Solution	Mean ± Std. Dev	95% Confidence Interval	p value
G-ænial A'CHORD	Distilled water	1.84 ± 0.38^{a}	1.51–2.15	< 0.001*
	Black coffee	3.34 ± 0.74^{b}	2.72–3.95	
	Coffee + bovine milk	$2.7 \pm 0.7^{a,b}$	2.10–3.28	
	Coffee + almond milk	2.97 ± 0.56^{b}	2.50–3.44	
	Coffee + oat milk	3.41 ± 0.14^{b}	3.28–3.52	
Omnichroma	Distilled water	0.8 ± 0.22^{c}	0.61–0.97	< 0.001*
	Black coffee	5.5 ± 0.68^{d}	4.93–6.06	
	Coffee + bovine milk	3.6 ± 0.53^{e}	3.15–4.04	
	Coffee + almond milk	$4.39 \pm 0.55^{e,f}$	3.92–4.84	
	Coffee + oat milk	4.44 ± 0.31^{f}	4.17–4.69	

*Welch ANOVA revealed significant differences among groups ($F(9, 27.866) = 123.580$, $p < 0.001$). Multiple comparisons were performed using Tamhane's T2 post-hoc test. Different superscript letters indicate statistically significant differences between groups ($p < 0.05$).

In both composite materials, beverage type showed a statistically significant effect on ΔE_{00} ($p < 0.001$; Fig. 2). In the G-ænial A'CHORD material, the highest color change values were observed in the oat milk coffee and black coffee groups, whereas the lowest values were obtained in the distilled water group. The distilled water group showed significantly lower ΔE_{00} compared to the black coffee ($p = 0.004$), almond milk coffee ($p = 0.005$), and oat milk coffee ($p < 0.001$) groups. However, the bovine milk coffee group showed no statistically significant difference when compared to the distilled water and other coffee groups ($p > 0.05$).

In the Omnichroma material, the highest color change values were observed in the black coffee group, followed by the oat milk coffee and almond milk coffee groups. The distilled water group showed significantly lower ΔE_{00} compared to the black coffee, bovine milk coffee, almond milk coffee, and oat milk coffee groups ($p < 0.001$ for all comparisons). The black coffee group showed significantly higher ΔE_{00} compared to the bovine milk coffee ($p < 0.001$), almond milk coffee ($p = 0.030$), and oat milk coffee ($p = 0.025$) groups. Furthermore, the oat milk coffee group showed significantly higher ΔE_{00} compared to

the bovine milk coffee group (p = 0.026). However, no significant difference was found between the almond milk coffee and bovine milk coffee groups, and between the almond milk coffee and oat milk coffee groups (p > 0.05).

Figure 2. Color change (ΔE_{00}) values of the tested composites after immersion in different beverage solutions (mean ± SD).

4.2. Surface Roughness (Ra) Results

Initial and 12-day immersion Ra values of composite resins are presented in Table 3.

Table 3
Comparison of initial and final surface roughness (Ra) values of composite resins.

Materials	Immersion Solution	Initial	Final	p value
		Median (Min-Max)	Median (Min-Max)	
G-ænial A'CHORD	Distilled water	0.09 (0.05–0.10)	0.10 (0.08–0.11)	0.122
	Black coffee	0.07 (0.05–0.10)	0.08 (0.06–0.10)	0.572
	Coffee + bovine milk	0.07 (0.05–0.11)	0.09 (0.05–0.12)	0.168
	Coffee + almond milk	0.08 (0.05–0.08)	0.06 (0.05–0.10)	0.453
	Coffee + oat milk	0.08 (0.05–0.09)	0.07 (0.05–0.07)	0.340
Omnichroma	Distilled water	0.07 (0.04–0.11)	0.10 (0.07–0.13)	0.071
	Black coffee	0.08 (0.06–0.11)	0.11 (0.10–0.12)	0.024*
	Coffee + bovine milk	0.11 (0.06–0.13)	0.08 (0.06–0.10)	0.068
	Coffee + almond milk	0.10 (0.09–0.12)	0.09 (0.06–0.12)	0.244
	Coffee + oat milk	0.08 (0.05–0.10)	0.07 (0.04–0.10)	0.121

Values are presented as median (min–max). Wilcoxon signed-rank test was used for baseline and post-immersion comparisons (*p < 0.05).

In the G-ænial A'CHORD material, no statistically significant difference was found between the initial and final Ra values in all groups (p > 0.05). In the Omnichroma material, however, a statistically significant increase in the final Ra value relative to the initial value was observed only in the black coffee group (p = 0.024). No significant difference was observed in the other groups (p > 0.05).

Comparative statistical data on the effects of coffee solutions containing different milk additions on the amount of change in surface roughness (ΔRa) of restorative materials are shown in Table 4.

Table 4
Comparison of the effects of different immersion solutions on surface roughness change (ΔRa) of the restorative materials.

Immersion Solution	Mean Rank	Test statistics	p value
Distilled water	58[a]		
Black coffee	51.22[a]		
Coffee + bovine milk	33.72[a,b]	21.081*	p < 0.001
Coffee + almond milk	30.88[b]		
Coffee + oat milk	28.69[b]		

Kruskal–Wallis H test revealed significant differences among groups (H(4) = 21.081, p < 0.001). Multiple comparisons were performed using Dunn–Bonferroni post-hoc test. Groups with different superscript letters within the same column were significantly different (p < 0.05).

Solution type had a statistically significant effect on ΔRa (p < 0.001). The highest ΔRa was observed in the distilled water and black coffee groups, while the lowest values were obtained in the almond milk coffee and oat milk coffee groups. As a result of multiple comparisons, it was determined that the distilled water and black coffee groups showed significantly higher ΔRa compared to the almond milk coffee and oat milk coffee groups (p < 0.05). In contrast, no statistically significant difference was found in the bovine milk coffee group when compared with the other groups (p > 0.05).

When the effect of material type on Ra in different solutions was analyzed, no statistically significant difference was found between composite types in the distilled water, black coffee, almond milk coffee, and oat milk coffee groups (p > 0.05). However, in the coffee group with added bovine milk, Omnichroma material exhibited a statistically significantly lower roughness change value than G-ænial A'CHORD material (p = 0.027).

The relationship between ΔRa and ΔE_{00} of restorative materials was examined; however, no statistically significant correlation was found between roughness and ΔE_{00} (r = -0.204, p = 0.070).

The findings showed a significant interaction between material type and applied medium for ΔE_{00} (F(4.70) = 20.870; p < 0.001). This finding was that Omnichroma material showed significantly higher ΔE_{00} in black coffee than G-ænial A'CHORD, but this difference decreased with the addition of milk.

5. Discussion

In this study, the effects of different coffee solutions on the color stability and Ra of monochromatic and nanohybrid composites were evaluated. Statistical analyses revealed that both the type of solution applied and the composite material structure significantly affected the parameters examined.

Accordingly, the null hypothesis that solution type and material type have no significant effect on color stability and Ra was rejected.

Monochromatic composites operate via a “structural coloration” mechanism that relies on the interaction of light with homogeneous spherical fillers approximately 260 nm in size, rather than traditional pigments (15). Although this technology offers high aesthetic compatibility, our study found that these materials can be sensitive to solutions with high chromogenic potential, such as coffee. Similarly, previous studies have reported significant color change in monochromatic composites after coffee immersion. Rohym et al. (16) reported high ΔE_{00} and Ra values in monochromatic composites after coffee immersion.

In the present study, Omnichroma material showed higher ΔE_{00} values compared to G-ænial A'CHORD material in all coffee-containing groups. In contrast, in the distilled water group, the ΔE_{00} value of G-ænial A'CHORD material was found to be higher than that of Omnichroma material. It is thought that the different filler distribution and resin matrix composition of the nanohybrid G-ænial A'CHORD material, in contrast to the optical structure of Omnichroma based on its structural coloring mechanism, may affect its coloring behavior. This indicates that the effect of material type on color stability may vary depending on the solution's chromogenic structure. Similarly to our study, Duzyol et al. (4) also reported that higher ΔE_{00} values were obtained in Omnichroma material compared to G-ænial A'CHORD after coffee exposure. This suggests that Omnichroma material may exhibit a more sensitive behavior towards chromogenic solutions.

In the study, the lowest ΔE_{00} values among the coffee-containing groups were obtained in the coffee group with added bovine milk in both materials. The stain-reducing effect of milk added to coffee may be related to the interaction of milk casein proteins with chromogenic pigments and to reduced pigment adhesion to the surface. This mechanism, described in the literature on natural tooth enamel, is reported to weaken the adhesion of pigments to the surface. Similarly, milk components may reduce the adhesion of coffee pigments to the composite surface and their penetration into the resin matrix (12, 15).

El Wakeel et al. (17) reported that coffee with milk resulted in lower ΔE values compared to black coffee. In a study by AlSheikh et al. (18) the coffee group with added milk was evaluated, and it was reported that coffee with milk resulted in lower ΔE_{00} than black coffee. In another study conducted by Kim (19) it was reported that adding bovine milk to coffee diluted the coloring agents and that casein in milk protected the tooth surface; this supports the low discoloration observed in the coffee group with added bovine milk in our study. This finding is similar to the lower ΔE_{00} values obtained in the coffee group with added bovine milk in our study.

On the other hand, Yanuarita et al. (20) reported that the low pH of probiotic milks caused degradation of the polymer matrix of composite resins and increased the material's liquid absorption, resulting in a significant ΔE_{00}. The researchers associated this situation with the disruption of matrix-filler bonds and increased dye penetration at low pH. In this context, it is thought that environmental acidity and whether

the milk is fermented may be determining factors in the effects of milk-containing beverages on composite resins.

In the plant-based milk groups, higher ΔE_{00} values were obtained in the coffee group with added oat milk compared to almond milk. This may be related to the high β-glucan content in oat milk, which increases its viscosity. High molecular weight β-glucan is reported to function as a strong thickening agent in oat-based beverages, significantly increasing the viscosity of the liquid (21, 22). The increased viscosity may have caused the chromogenic pigments in coffee to be retained on the restorative material surface for a longer period. This could facilitate the penetration of the pigments into the resin matrix, leading to higher ΔE_{00} values. Furthermore, the absence of casein-like pigment-binding proteins found in bovine milk in oat milk may also contribute to the coffee's more pronounced coloring effect. In addition, it is reported that plant-based beverages undergo more complex production processes compared to bovine milk and may contain various stabilizers, emulsifiers, and thickeners to improve their sensory properties (11). It is thought that these components may have contributed to the color behavior by influencing the interactions of the coffee's chromogenic pigments with the material surface.

In addition to color stability, Ra is another important parameter affecting the long-term clinical success of restorative materials. Ra is a critical indicator for both biofilm retention and aesthetic lifespan of restorations (2). In our study, it was determined that the Ra values obtained in all groups in both baseline and post-immersion measurements remained below the clinically acceptable limit of 0.2 μm (7). While no significant difference was found between initial and final Ra values in any group of the G-ænial A'CHORD material, a significant increase in Ra was observed only in the black coffee group of the Omnichroma material. This finding is consistent with studies reporting that chromogenic and acidic beverages, such as coffee, can cause matrix degradation and surface irregularities on composite resin surfaces. It has been reported that the acidic nature of black coffee can increase surface degradation and microcrack formation in composite resins (2). In our study, a certain level of ΔRa was also observed in the distilled water group. This may be related to water absorption arising from the resin matrix's hydrophilic structure and the resulting hydrolytic changes.

In contrast, no significant change was observed between the initial and final Ra values in the milk-added coffee groups. Furthermore, it was determined that the ΔRa values were lower in the almond milk and oat milk coffee groups than in the black coffee group. A lower ΔRa was also observed in the bovine milk coffee group compared to black coffee, but this difference was not statistically significant. It was found that the lipid, mineral, and soluble component contents of milk and plant-based milk alternatives differed. Moore et al. (11) reported that bovine milk had higher lipid, calcium, and phosphorus content than plant-based alternatives.

In contrast, almond and oat milks had different fatty acid profiles and higher carbohydrate ratios. It is thought that these physicochemical differences may have modified surface degradation by altering the interaction between coffee and the composite surface. In particular, the components present in the milk

types may have buffered the coffee's acidity, limiting water absorption and surface degradation in the resin matrix.

In our study, no statistically significant correlation was found between increased roughness and ΔE_{00}. This suggests that ΔE_{00} occurring in composite resins is not solely related to changes in surface topography. Lu et al. (23) reported that coffee-induced ΔE_{00} increased with increasing Ra in composite resins. This finding differs from ours because we found no direct relationship between Ra and ΔE_{00}. In contrast, Lee et al. (24) reported that discoloration in composites is affected not only by Ra but also by intrinsic material properties related to the resin matrix and filler structure. This finding is similar to the results of our study.

The findings support the limited literature on the effects of coffees prepared with plant-based milk alternatives on restorative materials. They can provide a basis for further studies in this field. However, the study has some limitations. The study was conducted under in vitro conditions, and the complex dynamics of the oral environment, such as saliva, thermal changes, mechanical abrasion, and pH fluctuations, could not be fully simulated. In addition, the continuous immersion model used does not directly reflect daily consumption habits. The effects of the components contained in plant-based milks on restorative materials were not directly analyzed. Therefore, further in vitro and clinical studies are needed to support the findings.

6. Conclusion

Omnichroma exhibited higher color change values than G-ænial A'CHORD, particularly in the black coffee and oat milk coffee groups. In contrast, G-ænial A'CHORD showed lower color change values across all coffee-containing groups. Among the tested coffee solutions, bovine milk coffee resulted in the lowest color change values in both materials. Surface roughness values remained within clinically acceptable limits across all groups; however, only the Omnichroma black coffee group showed a significant increase. Furthermore, no significant correlation was found between surface roughness and color change. These findings suggest that coffees prepared with plant-based milk alternatives may affect the aesthetic stability of resin-based composites differently than those prepared with bovine milk.

Abbreviations

ΔE_{00}
Color difference calculated using the CIEDE2000 formula
Ra
Surface roughness
ΔRa
Change in surface roughness
SD
Standard deviation

T_0
Baseline measurement
T_1
Final measurement
ANOVA
Analysis of Variance

Declarations

Ethics Statement

Not applicable.

Competing interests

The authors declare no competing interests.

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Figures

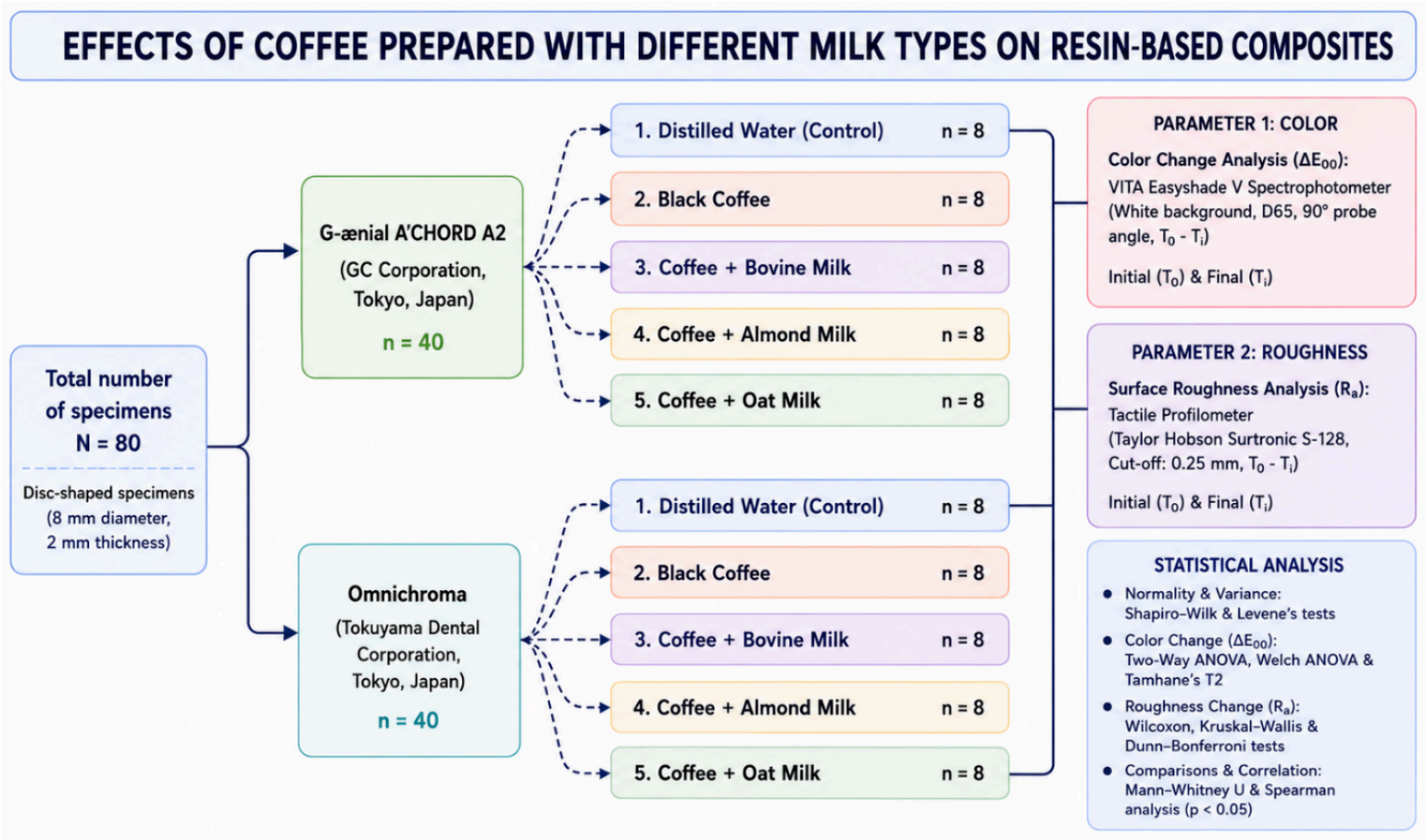


Figure 1

Study design and experimental workflow.

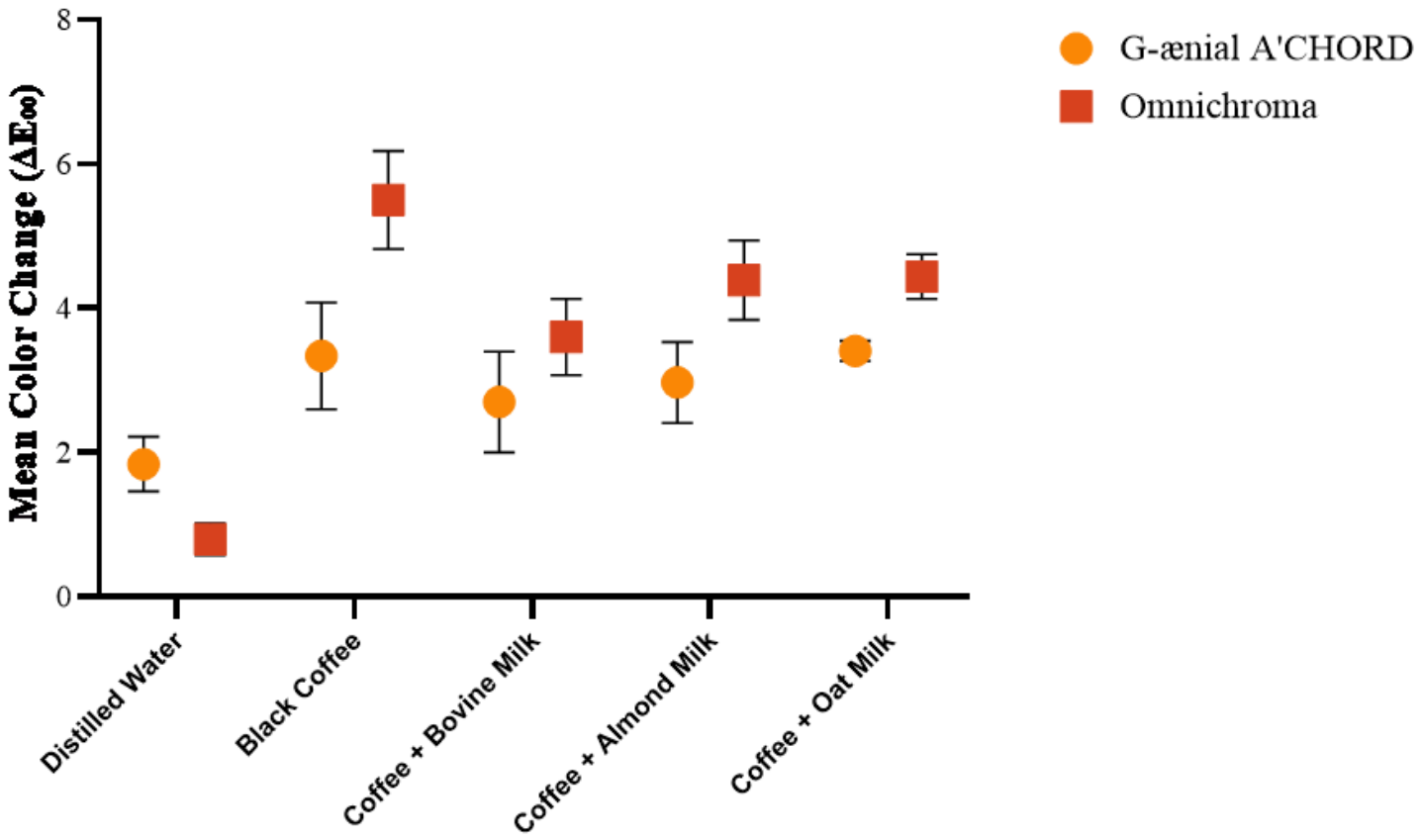


Figure 2

Color change (ΔE_{00}) values of the tested composites after immersion in different beverage solutions (mean ± SD).

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