Odovtos-International Journal of Dental Sciences (Odovtos-Int. J. Dent. Sc.), Online First, 2026. ISSN: 2215-3411
https://doi.org/10.15517/fd1z3227

ODOVTOS
International Journal of Dental Sciences

UNIVERSIDAD DE COSTA RICA
FOd Facultad de Odontología

https://revistas.ucr.ac.cr/index.php/rOdontos

BASIC RESEARCH:

Color Change and Compressive Strength of Novel Single-Shade Composite Resins Exposed to Staining Beverages

Cambio de color y resistencia a la compresión de nuevas resinas compuestas monocromáticas expuestas a bebidas pigmentantes

Juan P. Molina-Gantiva DDS[1] https://orcid.org/0000-0001-9837-6361
Midian C. Castillo-Pedraza DDS, Esp, MSc PhD[2] https://orcid.org/0000-0003-3170-3959
Jorge H. Wilches-Visbal Eng, Esp, MSc, DSc[2] https://orcid.org/0000-0003-3649-5079

[1]Dentist, University of Magdalena. Santa Marta, Colombia.
[2]Associate Professor. Dentistry Program, School of Health Sciences, University of Magdalena, Santa Marta, Colombia.

Correspondence to: Jorge H. Wilches-Visbal Eng, Esp, MSc, DSc - jwilches@unimagdalena.edu.co

Received: 11-II-2026 Accepted: 2-V-2026

ABSTRACT: Aim of this work was to evaluate the color change and mechanical compression resistance of two high-esthetic resin-based composites (single-shade composite (SSC) and conventional composite with spheroidal zirconium silicate (CC)) after immersion in coffee, red wine, and Coca-Cola, using artificial saliva as a control, over 7, 15, and 30 days. For color assessment, shade was recorded using the VITA 3D-Master system and converted to CIE L*a*b* coordinates to calculate color change (ΔE). Due to incomplete data at 15 and 30 days for some conditions, the temporal component was described descriptively, and a two-way ANOVA (resin × beverage) was applied. For compressive strength (MPa), disc-shaped specimens were tested using a universal testing machine, and a three-way ANOVA (resin × beverage × time) was performed. Results showed a progressive increase in discoloration, with greater magnitude in red wine and coffee, while Coca-Cola produced smaller and slower changes. Beverage type accounted for the largest proportion of variation in color change, and the resin-beverage interaction indicated differential responses depending on material type. Compressive strength varied with time and resin type, with small effect sizes and no significant interactions. Overall, the SSC exhibited higher compressive strength than the CC. In conclusion, clinical material selection should consider both dietary exposure to pigmented beverages and the resin type to minimize short- and medium-term esthetic and mechanical deterioration.

KEYWORDS: Composite resins; Color; Beverages; Coffee; Compressive strength.

RESUMEN: El objetivo de este estudio fue evaluar el cambio de color y la resistencia a la compresión de dos resinas compuestas de alta estética (composite de tono único (SSC) y composite convencional con silicato de zirconio esferoidal (CC)) tras su inmersión en café, vino tinto y Coca-Cola, utilizando saliva artificial como control, durante 7, 15 y 30 días. Para la evaluación del color, el tono se registró mediante el sistema VITA 3D-Master y se convirtió a coordenadas CIE L*a*b* para calcular el cambio de color (ΔE). Debido a datos incompletos a los 15 y 30 días en algunas condiciones, el componente temporal se describió de forma descriptiva, y se aplicó un ANOVA de dos vías (resina × bebida). Para la resistencia a la compresión (MPa), se ensayaron especímenes en forma de disco mediante una máquina universal de ensayos, y se realizó un ANOVA de tres vías (resina × bebida × tiempo). Los resultados mostraron un aumento progresivo de la decoloración, con mayor magnitud en vino tinto y café, mientras que la Coca-Cola produjo cambios menores y más lentos. El tipo de bebida explicó la mayor proporción de la variación en el cambio de color, y la interacción resina-bebida indicó respuestas diferenciales según el tipo de material. La resistencia a la compresión varió con el tiempo y el tipo de resina, con tamaños de efecto pequeños y sin interacciones significativas. En general, el SSC presentó mayor resistencia a la compresión que el CC. En conclusión, la selección clínica del material debe considerar tanto la exposición a bebidas pigmentadas como el tipo de resina, con el fin de minimizar el deterioro estético y mecánico a corto y mediano plazo.

PALABRAS CLAVE: Resinas compuestas; Color; Bebidas; Café; Resistencia a la compresión.

INTRODUCTION

Over the last decade, restorative dentistry has experienced sustained growth in the development of direct restorative materials aimed at maximizing esthetics without compromising mechanical performance, driven by increasingly demanding patient expectations and the need for predictable, long-lasting restorations (1). Within this landscape, resin-based composites have become the material of first choice due to their biocompatibility and their ability to reproduce the natural appearance of teeth, particularly in the anterior region (2). Nevertheless, the clinical performance of a restoration depends not only on its initial quality, but also on its optical stability and its resistance to everyday challenges in the oral environment.

Recent innovations include so-called high esthetics composites designed to simplify shade selection and enhance visual integration with the dental substrate. SSC, for instance, is a single-shade material intended to adjust its appearance to the surrounding tooth color through mechanisms related to the color adjustment potential described for single-shade composites and the structural color phenomenon (3,4). In addition, formulations incorporating specific inorganic fillers, such as conventional resin-based composites containing spheroidal zirconia silicate, have been proposed to optimize mechanical properties and facilitate polishing and gloss retention-attributes that are directly associated with mid-term esthetic outcomes (5). Despite their increasing use, evidence regarding their optical and mechanical behavior under simulated prolonged exposure conditions remains limited.

Advances in resin-based composites have led to the introduction of single-shade or omnichromatic materials designed to simplify shade selection while maintaining adequate esthetic integration (3,6). Unlike conventional composites, which rely mainly on pigments to generate color, these materials incorporate specific compositional and microstructural modifications that enable a chameleonic effect (6). This phenomenon is attributed to a combination of optimized filler size distribution, high filler loading, and refractive index matching between the organic matrix and inorganic fillers, modulating light scattering and transmission within the material (6,7). Additionally, some systems use structural color mechanisms derived from light-material interactions that enhance optical blending with surrounding dental tissues (3,6).

Color stability is a central determinant of clinical acceptability for resin composites, as discoloration is among the most frequent causes of esthetic dissatisfaction and restoration replacement (1,2). Commonly consumed beverages such as coffee, wine, and carbonated drinks contain chromogenic compounds and/or chemical conditions (e.g., acidity) capable of inducing surface changes and promoting adsorption or penetration of colorants (2,8). The literature indicates that immersion in staining beverages may alter surface roughness and optical parameters such as translucency, thereby affecting color perception and accelerating esthetic degradation (8). Moreover, the magnitude of color change has been reported to depend not only on the staining agent, but also on intrinsic material characteristics, including the organic matrix composition, the type and content of fillers, and variables associated with polymerization (2,9).

Beyond the optical dimension, the mechanical dimension is critical: although high-esthetics composites are frequently used in areas subjected to moderate loads, compressive strength remains a relevant indicator of structural performance and of the material's ability to withstand masticatory and parafunctional forces, consistent with evidence on the clinical behavior of posterior direct resin restorations (10). However, available evidence often addresses staining or mechanical performance in isolation, and integrated assessments simultaneously examining how the same staining environment may be associated with chromatic changes and mechanical behavior are less common, particularly for more recently introduced high-esthetics composites (11,12).

Therefore, the aim of this study was to evaluate, under controlled *in vitro* conditions, the color change and compressive strength of SSC and CC containing spheroidal zirconia silicate after exposure to commonly consumed staining beverages (coffee, Coca-Cola, and red wine), using a control medium. By comparing both materials and exploring the effect of beverage type, this study seeks to provide applied evidence to support material selection and clinical counseling regarding consumption habits that may compromise the esthetics and/or mechanical integrity of direct restorations.

The null hypotheses were: (1) there are no significant differences in color change between the tested resin-based composites; (2) the type of staining beverage does not significantly affect color change; (3) immersion time does not significantly influence color change; (4) there are no significant differences in compressive strength between the tested materials; and (5) staining beverage and immersion time do not significantly affect compressive strength.

MATERIALS AND METHODS

SPECIMEN PREPARATION AND IMMERSION MEDIA

This *in vitro* experimental study evaluated the color change and compressive strength of two resin-based composites subjected to different staining conditions over time. The study followed a factorial design in which resin type and staining beverage were considered as main factors for color assessment, while resin type, staining beverage, and immersion time were included for mechanical testing. Specimens were prepared and allocated according to the experimental groups described below.

Specimens were prepared from two resin-based composites: an omnichromatic (single-shade) composite (SSC: Vittra APS Unique, FGM, Joinville, SC, Brazil) and a conventional (multi-shade) nano-filled composite containing spheroidal zirconia silicate (CC: Vittra APS, FGM, Joinville, SC, Brazil). All specimens were fabricated as disc-shaped specimens (5 mm in diameter × 2 mm in thickness) using standardized plastic molds. The selected dimensions support adequate light curing and help minimize polymerization shrinkage-related stress, in line with commonly accepted recommendations for resin-based composites (13).

Specimens were subsequently light cured using an Elipar™ LED (3M, St. Paul, MN, USA) curing unit (irradiance: 1000 mW/cm²) for 20 s. After curing, each specimen was finished and polished using Sof-Lex™ discs (3M, St. Paul, MN, USA) following a standardized multi-step protocol with four grit sizes (coarse, medium, fine, and superfine). Each polishing step was applied for a consistent duration under constant manual pressure and continuous water irrigation to prevent overheating. All procedures were performed by a single trained operator to minimize variability and ensure uniform surface conditions across specimens. Specimen diameter and thickness were verified with a digital micrometer, and mass was recorded using an analytical balance to standardize specimens prior to testing.

The immersion media were as follows: coffee (instant coffee, Sello Rojo), Coca-Cola (original formulation), red wine (Gato Negro Cabernet Sauvignon), and artificial saliva (SALIVAR NF – FARPAG) as the control. Coffee was freshly prepared every morning to ensure freshness. Coca-Cola, red wine, and artificial saliva were stored at room temperature until use.

All solutions were renewed twice daily (08:00 and 20:00 h) to maintain consistent exposure conditions. Specimens were placed in labeled plastic containers with 24 compartments according to resin type, immersion medium, and exposure period. During immersion, containers were incubated at 37 °C to simulate the intraoral thermal environment.

EXPERIMENTAL GROUPS AND DESIGN

To evaluate color change (ΔE) and compressive strength, specimens from each resin (two levels) were allocated to four immersion media groups (artificial saliva, coffee, Coca-Cola, and red wine) and to three immersion periods (7, 15, and 30 days), resulting in a 2 × 4 × 3 factorial design (24 experimental groups) (Table 1).

Table 1. Experimental design for the assessment of color change (ΔE*ab) and compressive strength across immersion media and time points.

Variable	Levels	Details
Resin type	2	SSC; CC
Immersion media	4	Artificial saliva (control); Coffee; Coca-Cola; Red wine
Immersion time	3	7, 15, and 30 days
Factorial allocation	-	2 resins × 4 media × 3 time points=24 experimental groups
Sample size (n)	-	ΔE: 240 specimens (n=10 per group). Compressive strength: 480 specimens (n=20 per group). For compressive testing, n=20 per group was used to increase power and precision given the higher variability of the mechanical response

Source: own elaboration.

INSTRUMENTS AND OUTCOME ASSESSMENT

Compressive testing was performed using a materials testing machine (ME-8236, PASCO Scientific, Roseville, CA, USA), which measures force and displacement through an integrated load cell and displacement system (Figure 1).

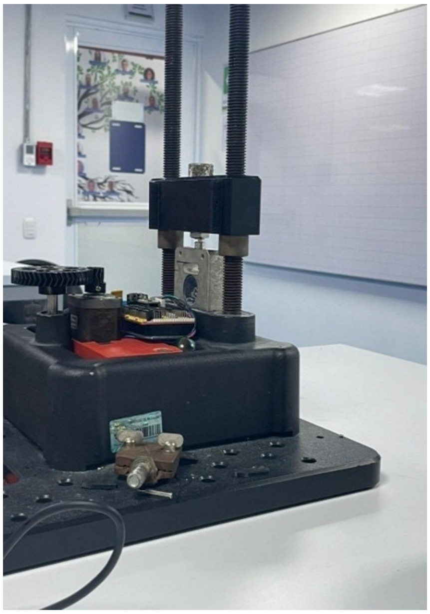

Figure 1. Schematic representation of the compressive strength test for the resin composites.

Disc-shaped specimens (5 mm in diameter × 2 mm in thickness) were used for this test, consistent with those used for color evaluation. The specimens were loaded along their longitudinal axis at a crosshead speed of 0.2 mm/min until failure.

Therefore, the results represent a comparative measure of compressive behavior under the conditions of this study and do not correspond to standardized compressive strength values according to ISO 4049.

The system was operated using PASCO Capstone software to record force-displacement data. The maximum load (N) at fracture was recorded and converted to compressive strength (MPa) by dividing by the specimen cross-sectional area ($A=\pi r^2$).

Color change was assessed visually using the VITA 3D-Master shade guide. Recorded shades were converted into CIE L*a*b* coordinates using a published conversion table derived from repeated spectrophotometric measurements per shade (e.g., five readings per shade and use of mean values) (14). Based on these coordinates, color difference was calculated as ΔE*ab (CIE76) (Euclidean distance in the CIELAB space) and interpreted according to the thresholds for perceptibility (ΔE≥2.6) and clinical acceptability (ΔE≥5.5).

Data were entered into Microsoft Excel and independently verified by two authors prior to exporting to the statistical software.

STATISTICAL ANALYSIS

Statistical analyses were performed assuming independent groups for both outcomes (compressive strength and color change). Model assumptions were assessed by testing residual normality (Shapiro-Wilk) and homogeneity of variances (Levene's test). Although minor departures from homoscedasticity were observed in some groups, the balanced design and sample size supported the use of the conventional ANOVA.

For color change (ΔE), a two-way factorial ANOVA was conducted with resin type and staining beverage/immersion medium as fixed factors, evaluating main effects and their interaction. Immersion time was not included as an inferential factor because complete observations were not available for all time levels across each resin–beverage combination (primarily due to limitations in ΔE recording in some groups at 15 and/or 30 days, when the color change was so pronounced that the shade fell outside the readable/convertible range), and therefore the temporal pattern of ΔE was described descriptively.

For compressive strength, given the availability of a complete and balanced dataset across the three immersion periods (7, 15, and 30 days), a three-way factorial ANOVA was performed with resin type, beverage/immersion medium, and immersion time as fixed factors, including main effects and interactions. P values, and partial eta-squared (η^2p) were reported. Model interpretation for both ΔE and compressive strength was supplemented, when appropriate, with estimated marginal means plots.

Statistical significance was set at $\alpha=0.05$. All analyses were conducted using Jamovi v. 2.3.28.4.

RESULTS

Two variables were analyzed: color change (ΔE) and compressive strength (R) for two high-esthetic resin composites (SSC and CC), immersed in four media (artificial saliva as control, Coca-Cola, coffee, and red wine) and evaluated at three time periods (7, 15, and 30 days).

COLOR CHANGE

Regarding color change, a progressive increase in discoloration over time was observed for both resin composites. Between the two materials, SSC showed a greater susceptibility to color change (except when immersed in Coca-Cola), whereas red wine exhibited the highest staining potential among the tested beverages (Table 2).

Table 2. Descriptive statistics of color change (ΔE) and compressive strength (R) in high-esthetic resin composites.

Resin	Medium	Time (days)	ΔE	R (MPa)
			(Mean ± SD)	
SSC	SA	7	-	188 ± 51.2
	SA	15	-	169 ± 73.5
	SA	30	-	199 ± 66.5
	CC	7	4.70 ± 3.018	193 ± 57.1
	CC	15	4.89 ± 3.243	152 ± 88.8
	CC	30	5.50 ± 1.041	175 ± 69.2
	CF	7	17.75 ± 3.906	164 ± 42.8
	CF	15	18.85 ± 1.794	146 ± 73.2
	CF	30	23.44 ± 1.685	182 ± 67.4
	VN	7	25.35 ± 2.341	170 ± 68.3
	VN	15	-	156 ± 93.4
	VN	30	-	178 ± 65.7
CC	SA	7	-	134 ± 41.1
	SA	15	-	141 ± 54.2
	SA	30	-	143 ± 43.7
	CC	7	3.06 ± 1.771	162 ± 71.6
	CC	15	7.04 ± 2.542	143 ± 74.4
	CC	30	12.73 ± 2.438	158 ± 60.2
	CF	7	11.42 ± 0.818	159 ± 48.5
	CF	15	14.85 ± 1.568	160 ± 72.6
	CF	30	-	146 ± 59.9
	VN	7	16.38 ± 1.795	163 ± 77.9
	VN	15	-	153 ± 62.4
	VN	30	-	179 ± 46.3

Note: SA: artificial saliva (control); CC: Coca-Cola; CF: coffee; VN: red wine. For ΔE, "—" indicates no recorded value (e.g., outside the measurement/conversion range) or not applicable (SA showed no color change during the evaluated periods, baseline condition).

SD: standard deviation.

Additionally, in all immersion media, the clinical perceptibility threshold was exceeded from day 7 onward (Figure 2).

When applying the two-way ANOVA and examining the estimated marginal means plot, both the immersion medium ($p<0.001$, $\eta^2p=0.770$) and the type of resin ($p<0.001$, $\eta^2p=0.273$) showed a significant effect on color change. In addition, a significant resin × medium interaction was observed ($p<0.001$, $\eta^2p=0.380$) (Figure 3).

COMPRESSIVE STRENGTH

Compressive strength values varied between resin types and immersion periods, whereas differences among immersion media were less consistent (Figure 4).

Overall, SSC exhibited higher mean compressive strength values than CC when considering the complete set of observations (Table 2 and Figure 4).

When applying the three-way ANOVA and examining the estimated marginal means plots, both immersion time ($p<0.001$, $\eta^2p=0.014$) and resin type ($p<0.001$, $\eta^2p=0.022$) showed a statistically significant effect on compressive strength, although with small effect sizes (13). In contrast, second-order interactions (resin × medium, resin × period, medium × period) as well as the three-way interaction (resin × medium × period) were not statistically significant (all $p>0.05$). Given the absence of interactions among factors, estimated marginal means were derived from the factorial model by introducing resin type and immersion period separately (Figure 5).

According to the marginal mean values, compressive strength showed a decrease at 15 days compared to 7 days, followed by a recovery at 30 days, reaching values similar to those at baseline. Furthermore, in the main effect by material, SSC exhibited greater strength than CC. Since no interactions were detected in the three-way ANOVA (all $p>0.05$), the results are interpreted in terms of main effects. On average, the effect of immersion time on compressive strength is consistent across the different immersion media and resin types; similarly, the effect of resin type remains consistent across the different immersion periods and beverages.

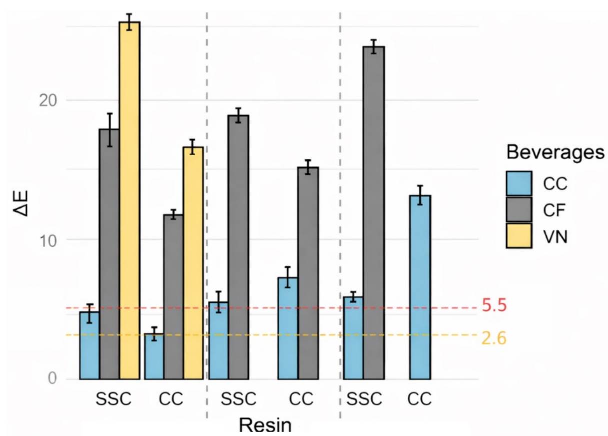

Figure 2. Color changes of composite resins subjected to staining beverages. The orange line (PT) indicates the perceptibility threshold (ΔE=2.6), and the red line (AT) represents the clinical acceptability threshold (ΔE=5.5). Dashed vertical lines separate the immersion periods.

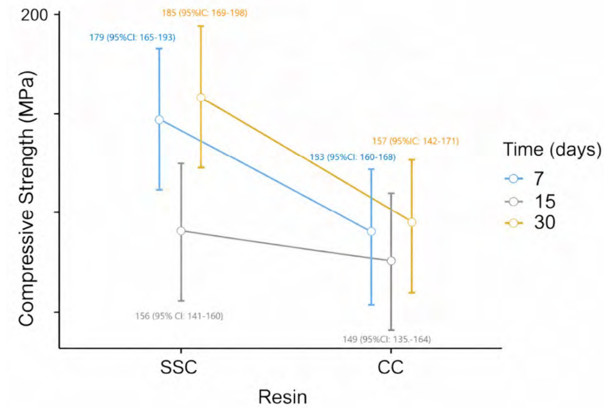

Figure 3. Estimated marginal means of color change (ΔE) as a function of resin type and immersion medium. The points represent the estimated mean ΔE values, and the vertical bars correspond to the 95% confidence intervals. Greater color changes were observed for red wine and coffee compared with Coca-Cola for both resin composites, along with a lower magnitude of discoloration for CC compared with SSC. Differences in slope between resins indicate a resin × medium interaction, suggesting that the effect of the immersion medium on color change depends on the restorative material.

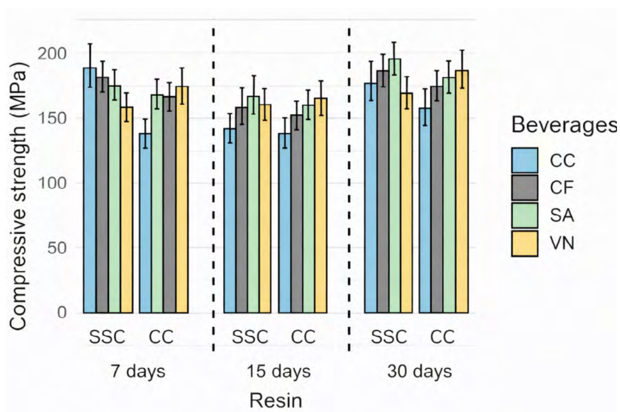

Figure 4. Compressive strength (MPa) of two high-esthetic composite resins (SSC and CC) after immersion in different beverages (CC: Coca-Cola, CF: coffee, SA: artificial saliva, VN: red wine) for 7, 15, and 30 days. Bars represent mean values, and error bars correspond to the standard error (SE). Dashed vertical lines separate the immersion periods.

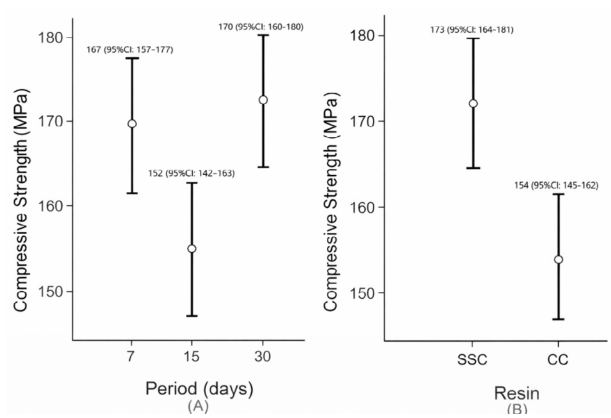

Figure 5. Estimated marginal means of compressive strength as a function of the main effects of the factorial model: (A) immersion period and (B) resin type. The points represent the adjusted means, and the vertical bars correspond to the 95% confidence intervals. Estimated marginal means were obtained from the factorial model while simultaneously controlling for the immersion medium, in accordance with the absence of statistically significant interactions among factors.

DISCUSSION

In recent years, restorative dentistry has expanded the range of composite resins designed to maximize esthetics without compromising mechanical performance, in response to increasing patient expectations and the demand for predictable, long-lasting restorations (15-18). Within this framework, an *in vitro* evaluation of color change (ΔE) and compressive strength in two high-esthetic composites (SSC and CC with spheroidal zirconium) immersed in four media (artificial saliva, Coca-Cola, coffee, and red wine) for three periods (7, 15, and 30 days) was conducted. For ΔE, resin and beverage were compared using a two-way ANOVA (resin×beverage), while the time component was described descriptively due to incomplete records in some groups. For compressive strength, a three-way factorial ANOVA (resin×beverage×time) was performed, including partial eta-squared ($\eta^2 p$) effect sizes and visualization through estimated marginal means.

COLOR CHANGE

The main finding was a progressive discoloration pattern over time in both resins, with greater magnitude in red wine and coffee and comparatively smaller changes in Coca-Cola, consistent with the behavior of organic-matrix materials exposed to oral chromophores and solvents (19-23). Red wine exhibited the highest staining potential from the earliest period evaluated, whereas coffee induced marked and progressive changes. This trend can be attributed to the combined effects of (i) pigment penetration/adsorption (e.g., tannins and polyphenols in wine; melanoidins in coffee), (ii) matrix softening and water sorption, and (iii) surface or matrix-filler interfacial degradation, which collectively facilitate pigment retention and increase ΔE (20-24). Conversely, Coca-Cola produced smaller and more slowly progressing changes. Although its acidity may promote surface softening or microstructural alterations, its chromophore load is typically lower than that of wine or coffee; therefore, its net staining effect is expected to be smaller, particularly when temperature is controlled and solutions are renewed to maintain constant exposure (22-26).

When comparing materials, SSC showed a higher tendency toward color change (except in Coca-Cola), whereas the spheroidal zirconium resin tended to be more resistant under highly staining media. This aligns with the notion that optical performance depends not only on the initial commercial shade but also on the interplay among the organic matrix, photoinitiator system, degree of conversion, filler size/distribution, and post-polishing surface roughness (17,18,23,27,28). In single-shade materials, the blending capacity (i.e., "color adjustment potential") may further deteriorate when sorption- and stain-driven changes alter translucency or internal light scattering (17,18,28-30). Overall, the immersion medium emerged as the primary determinant of ΔE, and material-related differences became more evident under strongly staining challenges.

From a methodological standpoint, color assessment based on visual VITA 3D-Master evaluation with subsequent conversion to CIE L*a*b* values represent a pragmatic approach that approximates clinical shade matching conditions. However, this method is inherently limited by observer variability and the indirect nature of the conversion process and therefore does not replace instrumental spectrophotometric measurements. Additionally, the use of the CIE76 (ΔE^*ab) formula, although widely adopted in earlier studies, may not fully reflect perceptual color differences compared to more advanced formulas such as CIEDE2000.

Consequently, the reported color differences should be interpreted as clinically oriented estimates rather than absolute colorimetric values.

COMPRESSIVE STRENGTH

Regarding compressive strength, the factorial analysis revealed significant main effects of time and resin type, with small effect sizes and no interactions. This indicates that, on average, the time-related change in compressive strength does not depend on the immersion medium or resin type, and that the mechanical superiority of one resin over the other remains consistent across beverages and periods. Estimated marginal means showed a reduction around 15 days with partial recovery at 30 days; however, in the absence of interactions, this pattern should be interpreted as an overall time effect rather than a response specific to a particular resin-beverage combination.

The consistently higher strength of SSC relative to the spheroidal zirconium resin may be attributable to formulation differences (matrix composition, inorganic loading, silanization quality, particle size distribution, and/or photopolymerization mechanisms), which govern stiffness, strength, and susceptibility to hydrolytic degradation (23,27,28). In aqueous or acidic environments, sorption may induce matrix softening and a transient reduction in mechanical properties; concurrently, post-curing phenomena or internal stress relaxation may contribute to partial recovery at later periods, particularly when degradation does not reach an irreversible threshold (27,29). Nevertheless, because strength was evaluated in independent groups at each period, a true longitudinal "recovery" at the specimen level cannot be claimed; rather, the findings represent between-group averages.

From a clinical standpoint, these results suggest that for high-esthetic composites, material selection should not rely solely on baseline mechanical properties but also on optical stability under realistic dietary habits. This is particularly relevant because esthetic failure due to staining is a frequent driver of restoration replacement, even in the absence of mechanical failure.

From a methodological perspective, flexural strength testing, particularly biaxial flexural testing, is considered more appropriate for evaluating the mechanical behavior of resin-based composites using disc-shaped specimens. In the present study, compressive testing was used to provide comparative assessment under consistent experimental conditions; therefore, the results should be interpreted with caution.

LIMITATIONS AND FUTURE DIRECTIONS

Key limitations include: (i) color estimation based on visual VITA 3D-Master assessment and conversion to CIE L*a*b*, combined with the use of the CIE76 (ΔE^*ab) formula, which, while clinically pragmatic, does not replace direct spectrophotometric measurement and may introduce observer-dependent variability and reduced perceptual accuracy; (ii) time was not included as an inferential factor for ΔE due to incomplete representation across time levels, limiting statistical inference on the temporal evolution of color; (iii) clinically relevant oral challenges-thermal cycling, toothbrushing abrasion, acquired pellicle, and fluctuations in pH and staining-agent concentration-were not comprehensively modeled; and (iv) compressive testing was performed using disc-shaped specimens rather than standardized cylindrical specimens as recommended by ISO 4049; therefore, the mechanical results should be interpreted as comparative rather than absolute values.

Future work should incorporate these aging components and assess in situ clinical performance under controlled diet, hygiene, and polishing conditions using longitudinal designs. Additionally, standardized mechanical testing approaches, such as biaxial or uniaxial flexural strength tests, should be incorporated to provide more robust and clinically relevant mechanical data.

CONCLUSION

Color change in both resins increased over time and was primarily driven by the type of beverage. Specifically, red wine and coffee produced the most intense and clinically meaningful chromatic changes from the earliest immersion periods, whereas Coca-Cola induced smaller alterations with slower progression. Between materials, a differential optical response was observed: the spheroidal zirconium formulation tended to exhibit greater stability under highly staining media, although the overall pattern remained largely conditioned by the staining challenge.

Regarding compressive strength, time and resin type showed statistically significant yet small effects, with no interactions, suggesting an overall behavior that is consistent across beverages and immersion periods. On average, SSC showed slightly higher mean compressive strength, although effect sizes were small. Clinically, restorative material selection should explicitly account for patients' habitual intake of staining beverages and the associated risk of short- to mid-term esthetic deterioration.

ARTIFICIAL INTELLIGENCE USE STATEMENT: Authors report limited use of ChatGPT (OpenAI) to improve clarity, grammar, and flow of selected manuscript sections. The AI tool did not generate data, perform analyses, or alter results; all scientific content and final decisions remain the authors' responsibility.

FUNDING: This research is self-financed.

CONFLICT OF INTEREST: None.

AUTHOR CONTRIBUTION STATEMENT: Conceptualization and design: M.C.C.P.; Literature review: J.P.M.G., M.C.C.P. and J.H.W.V.; Methodology and validation: J.H.W.V.; Writing-original draft preparation: J.P.M.L., M.C.C.P. and J.H.W.V.; Writing-review & editing: M.C.C.P. and J.H.W.V.; Supervision: J.H.W.V.

ACKNOWLEDGMENTS: Authors thank the Vice-Rectory for Research of the Universidad del Magdalena for institutional guidance and support for the implementation of the project (Project Initiation Record VIN 2024205) and Eng. Rafael J. Campo-Campo for the time devoted to compressive strength measurements.

REFERENCES

1. Romero H.J. Efecto de diferentes bebidas en la estabilidad de color de las resinas compuestas para restauraciones directas. Rev Ateneo Argent Odontol [Internet]. 2017; 56 (1): 31-43.
2. Morales-Lastre C.C., Castillo-Pedraza M.C., Wilches-Visbal J.H. Efecto de las bebidas pigmentantes sobre materiales restaurativos directos del sector posterior. Nova. 2023 May; 21 (40): 95-105.
3. Kobayashi S., Nakajima M., Furusawa K., Tichy A., Hosaka K., Tagami J. Color adjustment potential of single-shade resin composite to various-shade human teeth: Effect of structural color phenomenon. Dent Mater J. 2021; 40 (4): 1033-40.
4. Barros M.S., Silva P.F.D., Santana M.L.C., Bragança R.M.F., Faria-e-Silva A.L. Effects

of surrounding and underlying shades on the color adjustment potential of a single-shade composite used in a thin layer. Restor Dent Endod [Internet]. 2023; 48(1): 1-10. 10.5395/rde.2023.48.e7

5. FGM Dental Group. CC Silicato de zirconio esferoidal. 2023. p. 1-4.
6. Furusawa K., Kobayashi S., Yamashita A., Tichy A, Hosaka K, Shimada Y, et al. Effect of filler load on structural coloration and color adjustment potential of resin composites. Dent Mater J [Internet]. 2023 May 25; 42 (3): 2022-199. 10.4012/dmj.2022-199
7. Tripkis D., Humbel M., Deyhle H., Schulz G., Scheel M., Weitkamp T., et al. Hard x-ray nanotomography of dental composites for wide color matching. In: Lakhtakia A., Martín-Palma R.J., Knez M., editors. Bioinspiration, Biomimetics, and Bioreplication XIV [Internet]. SPIE; 2024. p. 27. 10.1117/12.3012813
8. Silva H., Arossi G., Damo D., Tovo M. Effect of Grape Derived Beverages in Colour Stability of Composite Resin Submitted to Different Finishing and Polishing Methods. Pesqui Bras Odontopediatria Clin Integr. 2017; 17 (1): 1-10.
9. Naoum S.J., Ellakwa A., Morgan L., White K., Martin F.E., Lee I.B. Polymerization profile analysis of resin composite dental restorative materials in real time. J Dent. 2012 Jan; 40 (1): 64-70.
10. Kruly P.C., Giannini M., Pascotto R.C., Tokubo L.M., Suga U.S.G., Marques A.C.R., Terada R.S.S. Meta-analysis of the clinical behavior of posterior direct resin restorations: Low polymerization shrinkage resin in comparison to methacrylate composite resin. PLoS One. 2018; 13 (2): e0191942.
11. Paolone G., Mandurino M., Scotti N., Cantatore G., Blatz M.B. Color stability of bulk-fill compared to conventional resin-based composites: A scoping review. J Esthet Restor Dent [Internet]. 2023 Jun 14; 35 (4): 657-76. 10.1111/jerd.13017
12. Alenezi A.Y., AlEyada A.M., Aldhafiri Y.H., Alsubaie M.S., Alshahrani M.S., Shenoy M. Color Stability of Tooth-Colored Restorative Materials After Exposure to Arabic Coffee and Black Tea: A Systematic Review. Cureus [Internet]. 2025 Sep 14; 17 (9): e92294. 10.7759/cureus.92294
13. Larraechea B., Rodríguez S., Toledo J. Técnica bulk-fill comparada con técnica incremental para restauraciones posteriores en pacientes con dentición permanente. Int J Interdiscip Dent. 2020 Dec; 13 (3): 196-200.
14. Budde N., Arnold C., Wienke A., Schweyen R. Comparison of the Clinical Evaluation of Digital Tooth Shade Determination Using an Intraoral Scanner with Proven Subjective and Objective Methods. J Clin Med [Internet]. 2024 Nov 6; 13 (22): 6668. 10.3390/jcm13226668
15. Duzyol M., Duzyol E., Çarıkçıoğlu B. Assessing one-shade composite resin color stability in response to everyday drinks. BMC Oral Health [Internet]. 2024 Jul 20; 24 (1): 821. 10.1186/s12903-024-04612-z
16. Ebaya M.M., Ali A.I., El-Haliem H.A., Mahmoud S.H. Color stability and surface roughness of ormocer- versus methacrylate-based single shade composite in anterior restoration. BMC Oral Health [Internet]. 2022 Sep 27; 22 (1): 430. 10.1186/s12903-022-02423-8
17. El-Rashidy A.A., Abdelraouf R.M., Habib N.A. Effect of two artificial aging protocols on color and gloss of single-shade versus multi-shade resin composites. BMC Oral Health [Internet]. 2022 Dec 1; 22 (1): 321. 10.1186/s12903-022-02351-7
18. Bilgili Can D., Özarslan M. Evaluation of color stability and microhardness of contem-

porary bulk-fill composite resins with different polymerization properties. J Esthet Restor Dent [Internet]. 2022 Sep 4; 34 (6): 924-32. 10.1111/jerd.12879

19. Sensi L., Winkler C., Geraldeli S. Accelerated Aging Effects on Color Stability of Potentially Color Adjusting Resin-based Composites. Oper Dent [Internet]. 2021 Mar; 46 (2): 188-96. 10.2341/20-099-L
20. Pedrosa M. da S., Nogueira F.N., Baldo V. de O., Medeiros I.S. Changes in color and contrast ratio of resin composites after curing and storage in water. Saudi Dent J [Internet]. 2021 Dec; 33 (8): 1160-5. 10.1016/j.sdentj.2021.02.002
21. Gurgan S., Koc Vural U., Miletic I. Comparison of mechanical and optical properties of a newly marketed universal composite resin with contemporary universal composite resins: An in vitro study. Microsc Res Tech [Internet]. 2022 Mar 12; 85 (3): 1171-9. 10.1002/jemt.23985
22. Lucena C., Ruiz-López J., Pulgar R., Della Bona A., Pérez M.M. Optical behavior of one-shaded resin-based composites. Dent Mater [Internet]. 2021 May; 37 (5): 840-8. 10.1016/j.dental.2021.02.011
23. Graf N., Ilie N. Long-term mechanical stability and light transmission characteristics of one shade resin-based composites. J Dent [Internet]. 2022 Jan;116:103915. 10.1016/j.jdent.2021.103915
24. Şahin H.C., Korkut B. Color adjustment of single-shade composites following staining, repolishing, and bleaching procedures. BMC Oral Health [Internet]. 2025 Feb 17; 25 (1): 248. 10.1186/s12903-025-05653-8
25. Islam M.S., Huda N., Mahendran S., Aryal A.C.S., Nassar M., Rahman M.M. The Blending Effect of Single-Shade Composite with Different Shades of Conventional Resin Composites-An In Vitro Study. Eur J Dent. 2023 May; 17 (02): 342-8.
26. Akgül S., Gündoğdu C., Bala O. Effects of storage time and restoration depth on instrumental color adjustment potential of universal resin composites. J Oral Sci [Internet]. 2022; 64 (1): 21-0290. 10.2334/josnusd.21-0290
27. Gornig D.C., Maletz R., Ottl P., Warkentin M. Influence of artificial aging: mechanical and physicochemical properties of dental composites under static and dynamic compression. Clin Oral Investig [Internet]. 2022 Feb 28; 26 (2): 1491-504. 10.1007/s00784-021-04122-0
28. Demarco F.F., Cenci M.S., Montagner A.F., de Lima V.P., Correa M.B., Moraes R.R., et al. Longevity of composite restorations is definitely not only about materials. Dent Mater [Internet]. 2023 Jan; 39 (1): 1-12. 10.1016/j.dental.2022.11.009
29. Rathod A., Vadavadagi S.V., Verma T., Kumar P., Deepak P.V., Deb S., et al. Effect of Acidic Beverages on Color Stability and Microhardness of Various Esthetic Restorative Materials: A Comparative Study. J Pharm Bioallied Sci [Internet]. 2021 Nov; 13 (Suppl 2): S1084-7. 10.4103/jpbs.jpbs_189_21
30. Barros M.S., Silva P.F.D., Santana M.L.C., Bragança R.M.F. de, Faria-e-Silva A.L. Effect of surrounded shade and specimen`s thickness on color adjustment potential of a single-shade composite. Braz Dent J [Internet]. 2022 Oct; 33 (5): 126-32. 10.1590/0103-6440202204973