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Chameleon Effect and Colour Stability of Nano-Filled Resin Composites: An *in-vitro* Study

(Kesan Kameleon dan Kestabilan Warna Komposit Resin Berisi Nano: Suatu Kajian *in-vitro*)

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ABSTRACT

This laboratory experimental study evaluated the chameleon effect and colour stability of three resin composites: SOLARE Sculpt (SL), Essentia (ES), and SimpliShade (SS), after immersion in distilled water, coffee, coke, and turmeric. Twenty class III restorations (shade A2) were placed on central incisors using the three materials and assessed for the chameleon effect with a digital colourimeter. To test colour stability, 120 circular specimens (10 mm diameter, 2 mm thickness) of each material (n=40) were immersed in distilled water, coke, coffee, and turmeric for 1, 7, and 30 days. Colour changes were measured using spectrophotometry. Results showed no significant differences in the chameleon effect among the materials ($p > 0.05$). However, colour stability varied significantly over time and across staining solutions. Turmeric caused the greatest discolouration, followed by coffee, Coke, and distilled water, with ES generally more susceptible to staining and SS showing the highest colour change in turmeric. These findings suggested that while the chameleon effect was similar across all materials, colour stability varied, with coffee and turmeric contributing more to staining. Clinicians can use this information to select materials based on patients' dietary habits and emphasize the importance of routine restorative maintenance for long-term aesthetic outcomes.

Keywords: Blending effect; chameleon effect; colour stability; resin composite; staining

ABSTRAK

Penyelidikan uji kaji makmal ini menilai kesan kameleon dan kestabilan warna tiga komposit resin: SOLARE Sculpt (SL), Essentia (ES) dan SimpliShade (SS), selepas rendaman dalam air suling, kopi, kok dan kunyit. Dua puluh pemulihan kelas III (teduh A2) diletakkan pada gigi kacip tengah menggunakan ketiga-tiga bahan tersebut dan dinilai untuk kesan kameleon dengan colourimeter digital. Untuk menguji kestabilan warna, 120 spesimen bulat (diameter 10 mm, ketebalan 2 mm) setiap bahan (n=40) telah direndam dalam air suling, kok, kopi dan kunyit selama 1, 7 dan 30 hari. Perubahan warna diukur menggunakan spektrofotometri. Keputusan menunjukkan tiada perbezaan yang signifikan dalam kesan kameleon antara bahan-bahan yang dikaji ($p > 0.05$). Namun, kestabilan warna berbeza secara signifikan mengikut masa dan jenis larutan pewarna. Kunyit menyebabkan perubahan warna paling ketara, diikuti oleh kopi, Coke dan air suling, dengan ES secara umumnya lebih mudah mengalami pewarnaan manakala SS mencatatkan nilai perubahan warna tertinggi dalam kunyit. Penemuan ini mencadangkan bahawa walaupun kesan kameleon adalah serupa pada semua bahan, kestabilan warna berbeza-beza dengan kopi dan kunyit menyumbang lebih banyak kepada pewarnaan. Pakar klinik boleh menggunakan maklumat ini untuk memilih bahan berdasarkan tabiat pemakanan pesakit dan menekankan kepentingan penyelenggaraan pemulihan rutin untuk hasil estetik jangka panjang.

Kata kunci: Kesan campuran; kesan kameleon; kestabilan warna; komposit resin; pewarnaan

INTRODUCTION

Resin composites are a preferred material in modern dentistry, offering a versatile and aesthetic alternative to traditional options. Since their introduction by Dr. Rafael Bowen in 1963, they have evolved to mimic natural teeth's physical and mechanical properties, with improvements such as enhanced strength, reduced polymerization shrinkage, and a thermal expansion coefficient similar to natural tooth structures, making them ideal for anterior and posterior restorations (Ferracane 2024). Additionally, advancements in filler technology and resin formulations have further enhanced their clinical performance.

With the growing demand for aesthetic dentistry, resin composites replicate natural optical properties, including colour, translucency, and surface texture, allowing seamless blending with natural teeth, particularly in anterior restorations. Their enhanced mechanical properties also make them suitable for posterior restorations, where strength and wear resistance are essential (AlHamdan et al. 2021; Aminoroaya et al. 2021). The ability to provide both functional and aesthetic benefits has contributed to their widespread use in restorative dentistry.

Despite advancements, achieving a perfect colour match remains challenging due to the wide range of natural tooth shades influenced by factors like age and health. Techniques like layering multiple composite shades address this but are time-intensive and technique-sensitive (Dietschi & Fahl 2016). Factors such as lighting conditions and operator experience can impact effective shade selection and the accuracy of shade matching.

The 'chameleon effect' is a breakthrough in colour matching, allowing resin composites to adapt to adjacent tooth structures, enabling natural-looking restorations with fewer shades. Nano-filled resin composites enhance this effect by mimicking the light transmission, diffusion, and reflection properties of enamel. While effective *in situ,* the effect is less reliable in isolated restorations. Nonetheless, it enables single-shade restorations in approximately 90% of cases (Tsubone et al. 2012). Advances in nanotechnology have played a significant role in achieving these properties, making the materials more reliable and predictable in clinical use.

Using fewer shades simplifies the restorative process and increases predictability, though achieving optimal aesthetics depends on material selection, application precision, and tooth colour. However, colour stability remains another challenge, as staining from food, beverages, and environmental factors can compromise aesthetics over time. Therefore, resin composite materials must combine excellent chameleon effects with long-term colour stability (Fathima, Hashir & Padmanabhan 2024). The ability to resist staining while preserving optical properties is crucial for ensuring long-term patient satisfaction.

This study compared the chameleon effect and colour stability of three nano-filled resin composites: SOLARE Sculpt, SimpliShade, and Essentia. SOLARE Sculpt, introduced in 2017 by GC Industrial, serves as the control due to its well-established performance, including superior wear resistance, marginal adaptation, and colour-matching capabilities (Afraaz et al. 2020; Rao et al. 2023; Tanaka et al. 2020). SimpliShade (2020), which incorporates Adaptive Response Technology (ART), provides effective colour matching across three shades, while Essentia (2023) features a universal shade designed for seamless blending. Each material employs a distinct formulation strategy aimed at enhancing both aesthetics and longevity in diverse clinical applications.

The study investigated the chameleon effect and colour stability of these three resin composites by evaluating colour changes following immersion in four different solutions: distilled water, coke, coffee, and turmeric, at various time intervals. The null hypotheses for this study were: (i) There is no significant difference in the chameleon effect among the three resin composites, and (ii) There is no significant difference in the colour stability of the composites after immersion in the different solutions. The findings of this study will assist dental practitioners in selecting materials and enhance aesthetic outcomes in restorative dentistry.

MATERIALS AND METHODS

The materials evaluated in this study and their technical profiles are shown in Table 1. The study was divided into two parts: the chameleon effect and colour stability.

SAMPLE SIZE

Sample size was calculated using GPower version 3.1.9.7. For the t-test comparison of chameleon effect, an effect size of d = 0.91, $\alpha = 0.05$, and power = 0.955 were used, yielding a required sample size of 10 per group. For the colour stability analysis, a two-way ANOVA design with an effect size f = 0.255, $\alpha = 0.05$, and power = 0.955 determined a total sample size of 120 (10 per group across 12 groups).

PART 1: CHAMELEON EFFECT

Preparation of specimens

Class III cavities were prepared on 20 acrylic maxillary central incisors (Yamahachi Dental, Aichi, Japan) with Vita Classical shade A2 using a 2.9 mm FG (Friction Grip) diamond bur (NTI-Kahla, Germany) for the visual comparison of two resin composite restorations on the same tooth (Table 2). The depth and location were standardized using an FG round diamond bur, which fully penetrated the teeth while avoiding the palatal surface (Figure 1). After preparation, the teeth were cleaned with an air/water spray and dried with compressed air (de Abreu et al. 2020). Three resin composites (Figure 2) used to restore the cavities in a single increment and were cured for 20 s with a 2 mm curing distance on the labial surface using a calibrated Radii Cal LED curing light (SDI, Victoria, Australia), emitting 1200 mW/cm² at 440-480 nm. Each specimen was stored in closed plastic containers at 37 °C.

Photographic analysis

Digital photos were taken using a Nikon D5600 camera with a 90 mm lens (AF 90 mm F/2.8 1:1 Macro, Tamron) and dual flash (MF12-DK1 Macro dual flash, Godox) (Figure 3). Cross-polarizing filters were placed on both sides of the camera for consistency. The camera was mounted on a tripod at a 45-degree angle with the following settings: 1/125 second exposure, f/25 aperture, ISO 400, manual flash at 1/2 power, a 45 cm shooting distance, and 1:1 focusing in RAW format. Photos were saved to an SD card and transferred to a computer for colour matching analysis.

Two colour measurements were taken: one at the centre of the restoration, 1 mm from the tooth/restoration margin

TABLE 1. Technical profiles of the materials used in this study

Material, Abbreviation	Manufacturer	Composition	Shade
SOLARE Sculpt, SL (Control)	GC Industrial Co., Tokyo, Japan	Resin: Bis-GMA, Bis-MEPP, UDMA, TEGDMA Fillers: Silica fine particle, barium glass, pre-polymerized filler, pigments, photo initiator	A2
Essentia, ES	GC Industrial Co., Tokyo, Japan	Resin: UDMA, Ytterbium trifluoride, BIS-MEPP, BIS-EMA, Bis-GMA, TEGDMA Fillers: pre-polymerized silica and barium glass (81% weight or 65% volume)	Universal
SimpliShade, SS	Kerr, Orange, USA	Resin: Bis-EMA, Bis-GMA, TEGDMA Fillers: Chemically infused mixed oxides, pre-polymerized filler, barium glass filler, silica, ytterbium trifluoride (81.5% weight or 65.1% volume)	Light

Bis-MEPP: Bisphenol-A-ethoxylate dimethacrylate; UDMA: Urethane dimethacrylate, Bis-GMA: Bisphenol-A-diglycidyl methacrylate, TEGDMA: Triethyleneglycol dimethacrylate, Bis-EMA: Bisphenol-A-diglycidyl methacrylate ethoxylated

TABLE 2. Experimental groups for colour matching evaluation

Group	Resin composite	Shade of acrylic tooth
A	SL & ES	A2
B	SL & SS	A2

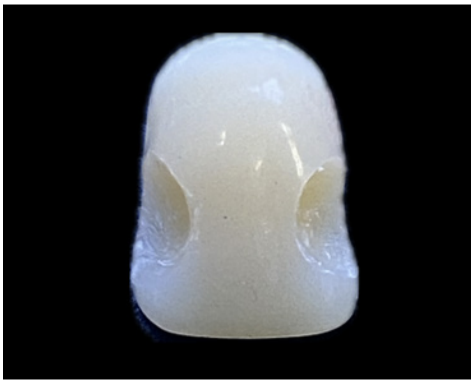

FIGURE 1. Representative image of class III preparation

FIGURE 2. Representative image of colour acquisition

towards the mesial or distal side, depending on orientation, and another at the tooth surface, 1 mm from the margin near the interface to minimize surface changes by reflected light (Figure 2). CIELAB values were measured using Classic Colour Metre version 2.1.1 for Mac, developed by Ricci Adams, selected for its ability to represent parameters in the CIELAB colour space (Figure 4) (Sanchez 2023).

The outcomes, L*, a*, and b*, represented the colour attributes: L* denotes lightness (0 = black, 100 = white), a* indicates the red-green axis (negative = green, positive = magenta), and b* represents the yellow-blue axis (negative = blue, positive = yellow). The equation herewith was applied to evaluate the colour difference between the tooth surface and the restoration (ΔE) (Usha, Rao & George 2018):

$$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2} \quad (1)$$

PART 2: COLOUR STABILITY

Preparation of specimens

A total of 120 circular specimens (40 specimens per group) were prepared using stainless-steel mould. The composite was packed in a single increment, compressed with Mylar strips and a 1 mm glass slide to create a smooth surface and prevent oxygen inhibition. Finger pressure was applied to ensure material adaptation and the extrusion of excess composite. Polymerization was performed using Radii Cal LED Curing Light (SDI, Victoria, Australia) at 1200 mW/cm² and 440-480 nm. A 1.0 mm glass slide was used to maintain the curing distance. Two 20-s overlapping exposures were applied to cure the top surface, followed by 20 s for the bottom. Finishing and polishing were performed using Sof-Lex™ discs (3M ESPE, Minnesota, USA) from coarse to superfine, each applied for 20 s in dry, circular motions. Only one surface was polished, and the unpolished side was marked. All steps were standardised by a single operator.

Immersion solutions preparation

The immersion solutions are shown in Figure 5. The coffee solution (Nestlé, Vevey, Switzerland) was prepared by dissolving 5 g of coffee in 250 mL of distilled water at 100 °C and stirring vigorously for 10 min (Yannikakis et al. 1998). The turmeric solution was made by boiling 0.1 g of turmeric powder (Baba's, Kuala Lumpur, Malaysia) in 100 mL of distilled water for 10 min, then straining it with a tea sieve to remove solids (Usha, Rao & George 2018). Cola solution (Coca-Cola, Georgia, USA) and distilled water were used as received. The solutions were stirred daily and replaced every three days to prevent contamination and maintain consistency. Each petri dish contained 10 specimens per composite, immersed at 37 °C. Specimens were rinsed under running water for 5 min and dried after immersion at 24 h, 7 days, and 30 days.

Colour assessment

The specimens' colour was evaluated at four time points: before immersion, 24 h, 7 days, and 30 days, using a digital colour Spectrophotometer CM-5 (Konica Minolta, München, Germany). Each sample was placed on the 3 mm diameter illumination area, and reflectance values were measured 1 s after illumination with a xenon lamp. A single reading was taken per sample against a black background. Changes in L*, a*, and b* (Δ) were calculated before and after immersion in the stain solution to assess colour stability using the CIELAB colour-difference equation (Usha, Rao & George 2018) as described in Part 1.

DATA ANALYSIS STRATEGY

The statistical analysis was carried out using SPSS version 27.0 (IBM SPSS Inc, Chicago, IL, USA). Kolmogorov-Smirnov test was performed to check for normality of data. For the chameleon effect, an independent t-test was used for statistical analysis, as the data followed a normal distribution. In contrast, the statistical analysis for colour stability was performed using the Kruskal-Wallis test due to the non-normal distribution of the data, followed by Bonferroni correction for multiple comparisons.

RESULTS AND DISCUSSION

PART 1: CHAMELEON EFFECT

The Kolmogorov-Smirnov test ($p<0.05$) indicated that the data were normally distributed, and the independent t-test was used for statistical analysis. The means and standard deviations of colour differences between SL and ES, as well as SL and SS were calculated and presented in Table 3. There was no significant difference (p-value>0.05) in the colour variation between SL and ES. When comparing SS to SL, the result suggested no significant colour difference ($p>0.05$) between the two composites. For colour difference (ΔE), ES showed the least ΔE value (3.37±1.40), followed by SL and SS, with SL as the reference.

PART 2: COLOUR STABILITY

The Kolmogorov-Smirnov test ($p < 0.05$) indicated that the data were not normally distributed; therefore, the Kruskal-Wallis test with Bonferroni correction was used for statistical analysis. Table 4 presents the means, standard deviations, and p-values of colour differences (ΔE) for each composite resin immersed in four different staining solutions- distilled water, Coke, coffee, and turmeric - at 24 h (D1), 7 days (D7), and 30 days (D30).

In distilled water, all materials exhibited minimal colour change over time, with no statistically significant differences observed between groups at D1 ($p = 0.376$), although ES showed a significant increase in ΔE by D30

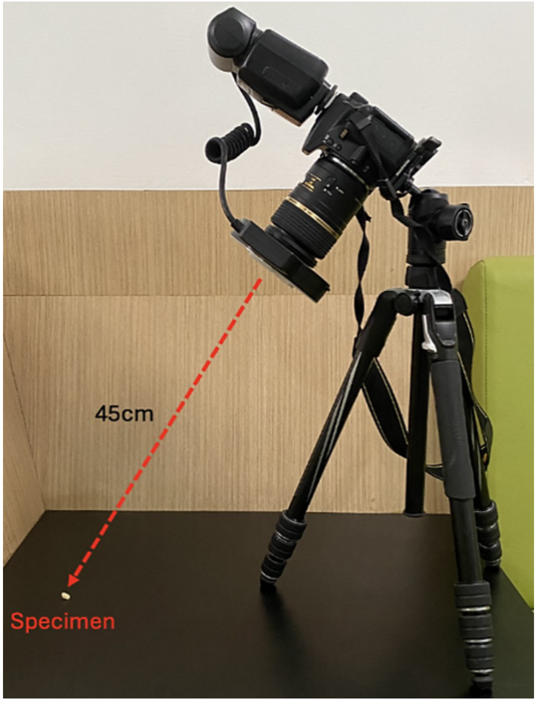

FIGURE 3. Set up for the photographic analysis

FIGURE 4. CIELAB colour coordinates

FIGURE 5. Immersion solutions used in this study

($p < 0.001$). SL and SS demonstrated relatively stable ΔE values with no significant changes ($p = 0.15$ and $p = 0.497$, respectively).

In Coke, colour change remained below perceptible thresholds for most groups, though ES and SL both showed statistically significant increases in ΔE from D1 to D30 ($p = 0.006$ and $p = 0.007$, respectively). The between-group comparison at D30 was significant ($p < 0.001$), with SS exhibiting higher ΔE than SL and ES.

In coffee, all materials showed substantial increases in ΔE values over time. ES demonstrated the greatest discolouration ($\Delta E = 11.74 \pm 1.25$ at D30), followed by SS ($\Delta E = 7.19 \pm 1.34$) and SL ($\Delta E = 6.29 \pm 1.29$). The differences between groups were statistically significant at D7 and D30 (both $p < 0.001$). Within-group comparisons over time also showed significant increases for all materials ($p < 0.001$).

In turmeric, the most intense staining was observed. SS recorded the highest ΔE (48.18 ± 3.49 at D30), followed by ES (45.64 ± 2.46) and SL (42.54 ± 1.43). Although all materials experienced a rapid and significant colour change from D1 to D7 ($p < 0.001$), the differences between materials were statistically significant at D7 and D30 ($p = 0.001$ and $p < 0.001$, respectively). Overall, turmeric produced the greatest colour change, followed by coffee, Coke, and distilled water. Across all staining media, ES generally showed higher susceptibility to staining compared to SL, while SS often exhibited the highest colour change in turmeric.

As for discussion, satisfactory aesthetic outcomes with resin composites depend on more than just accurate shade selection, and they also require materials with stable colour properties over time. Choosing the appropriate material is essential to reduce colour discrepancies between the tooth structure and restorative material, as such mismatches can result in increased costs and patient dissatisfaction (Cubukcu, Gundogdu & Gul 2023). This study evaluated the chameleon effect and colour stability of various nano-filled resin composites.

Colour perception is a complex phenomenon influenced by the observer's skills and can vary across different occasions. To mitigate discrepancies in colour evaluation, colour measurement devices were employed, using the CIELAB system, which includes three-dimensional colourimetric measurements: L* for brightness, a* for red-green content, and b* for yellow-blue content (Pratap et al. 2019). Colour changes (ΔE) were calculated from these values using the CIE76 colour difference formula.

The chameleon effect in resin composites allows these materials to adapt and blend seamlessly with surrounding natural teeth. The development of single-shade composites was driven by the need to simplify the colour matching process, reducing the reliance on multi-shade composite materials. This effect is achieved through nano-fillers that replicate the natural light transmission, diffusion, and reflection mechanisms within the tooth (Chen et al. 2020). However, resin composites may appear distinctly different from natural teeth when viewed in isolation (Tsubone et al. 2012).

TABLE 3. The mean colour differences and standard deviation between composites

Comparison	ΔE	p-value	95% CI	Cohen's d
SL vs ES	SL: 3.83±1.25	0.776	[3.030 - 4.101]	0.13
	ES: 3.37±1.40		[2.604 - 4.845]	
SL vs SS	SL: 3.57±0.75	0.443	[2.369 - 4.370]	0.35
	SS: 3.72±1.57		[2.939 - 4.731]	

SL: SOLARE Sculpt; ES: Essentia; SS: SimpliShade

TABLE 4. The mean colour differences and standard deviations of different composites immersed in different staining solutions at different time points

	Distilled Water				Coke				Coffee				Turmeric			
Material	D1	D7	D30	p-value	D1	D7	D30	p-value	D1	D7	D30	p-value	D1	D7	D30	p-value
ES	$0.51^{Aa} \pm 0.30$	$1.44^{Bab} \pm 0.30$	$2.16^{Ab} \pm 0.36$	<0.001	$0.43^{Aa} \pm 0.35$	$0.57^{Bab} \pm 0.35$	$0.83^{Ab} \pm 0.46$	0.006	$3.35^{Aa} \pm 1.03$	$8.50^{Aab} \pm 1.03$	$11.74^{Ab} \pm 1.25$	<0.001	$32.16^{Aa} \pm 2.77$	$45.16^{ABb} \pm 2.77$	$45.64^{Ab} \pm 2.46$	<0.001
SL	$0.43^{Aa} \pm 0.35$	$0.57^{Aa} \pm 0.35$	$0.83^{Ba} \pm 0.46$	0.15	$0.73^{Ba} \pm 0.48$	$0.73^{Ba} \pm 0.48$	$0.71^{Ab} \pm 0.37$	0.007	$2.38^{Aa} \pm 0.37$	$4.62^{Bab} \pm 0.37$	$6.29^{Bb} \pm 1.29$	<0.001	$21.61^{ABa} \pm 3.04$	$41.90^{Ab} \pm 3.04$	$42.54^{Bb} \pm 1.43$	0.007
SS	$0.73^{Aa} \pm 0.48$	$0.73^{Aa} \pm 0.48$	$0.71^{Ba} \pm 0.37$	0.497	$0.51^{Aa} \pm 0.30$	$1.44^{Aa} \pm 0.30$	$2.16^{Ba} \pm 0.36$	0.301	$2.84^{Aa} \pm 0.89$	$5.83^{Bab} \pm 0.89$	$7.19^{Bc} \pm 1.34$	<0.001	$32.93^{Ba} \pm 3.49$	$47.92^{Bb} \pm 2.61$	$48.18^{Bac} \pm 3.49$	<0.001
p-value	0.376	<0.001	<0.001		<0.001	<0.001	<0.001		0.125	<0.001	<0.001		0.024	0.001	<0.001	

Different uppercase letter within each column indicates significant difference. Different lowercase letter within each row indicates a significant difference. Adjusted p-value (Bonferroni correction). Abbreviation: SL: SOLARE Sculpt; ES: Essentia; SS: SimpliShade

In this study, SOLARE Sculpt was selected as the control due to its longer market presence and established reputation compared to SimpliShade (2020) and Essentia (2023). Numerous studies have demonstrated the exceptional colour-matching ability and stability of SOLARE Sculpt (Rao et al. 2023; Tanaka et al. 2020), solidifying its position as the gold standard among resin composites.

No significant colour difference was observed between SL and ES ($p>0.05$), indicating that both materials can achieve similar aesthetic outcomes. Similarly, the p-value ($p>0.05$) between SL and SS showed no significant statistical difference. The absence of significant differences in the chameleon effect among ES, SS, and SL suggests that these materials have similar aesthetic properties in mimicking natural tooth structure. This finding aligns with prior research on modern composites' advanced colour-matching capabilities, allowing clinicians to select materials based on cost, availability, and patient needs without compromising aesthetics. However, some studies have indicated multi-shade composites often outperform single-shade options, as seen when SL showed a better colour match than SS (Ismail & Paravina 2021). While all resin composites produced harmonious restorations, SL and SS showed clinically perceptible colour changes ($\Delta E > 3.3$) with acrylic teeth, except for ES, which had a ΔE value of 3.37 ± 1.40 (Al-Shami et al. 2023). ES exhibited the least ΔE value, suggesting its superior colour-matching properties among the three materials.

Cavity size and colour contrast with surrounding teeth may influence resin composite performance, as smaller cavities enhance blending for aesthetic results (Ismail & Paravina 2021). The inclusion of nano-fillers in composites also plays a crucial role, with nano-filled resins adapting more effectively to underlying tooth colour when layered, influenced by factors like restoration thickness, resin type, and colour contrast (Humbel et al. 2022). Nano-fillers enhance light diffusion and translucency, mimicking natural tooth structure. For instance, spherical silica-zirconia fillers optimize light interaction, while high-translucency composites further improve colour adaptation (Bakti et al. 2018; Ismail & Paravina 2021). Nano-filled composites provide exceptional blending effects, simplifying shade-matching and inventory management. These resin composites are highly recommended for direct restorative procedures, particularly in anterior restorations, due to their seamless integration with natural teeth, improving final outcomes.

Colour changes in restorative materials depend on composition, immersion time, and solution type. All resin composites in this study experienced discolouration, with varying severity depending on the immersion solution (Al-Shami et al. 2023). Turmeric, commonly used in South Asian cuisine, caused the highest colour change in SS and the most severe discolouration among all composites, which was consistent with results from Stober et al. (2011) and Yew and QamaruzZaman (2012) on severe discolouration with 0.1% turmeric solution and curry. Curcumin was identified as the principal pigment responsible for the deep orange colour in the specimens (Yew & QamaruzZaman 2012).

Coffee, widely consumed and known for its intense discolouration, showed ES as the most susceptible to colour change after one day of immersion, with clinically perceptible changes ($\Delta E>3.3$) (Al-Shami et al. 2023) and a ΔE value of 11.74 ± 1.25 after 30 days. These findings are consistent with Lim et al. (2025) who also reported significant colour change in single-shade composites following prolonged coffee immersion, highlighting ongoing challenges in maintaining long-term colour stability. Coffee contains tannins, a type of polyphenol that dissolves in water and a subgroup of phenolic compounds that contribute to the yellowish discolouration (Poggio et al. 2017). For coke and distilled water, pairwise comparisons showed no significant difference ($p>0.05$) in causing colour change in all composites. Coke contains caramel, a weak colourant, but its high acidity damages restoration surfaces, contributing to minimal discolouration due to the roughened surface.

Discolouration, which is considered as aesthetic failures, occurs due to external pigments and internal factors like resin matrix alterations or incomplete polymerization (AlHabdan et al. 2022). Inorganic fillers, when they separate from the resin matrix, form voids, leading to an increase in surface roughness. Nano-filled composites are more resistant to staining, as smaller filler sizes reduce colour changes compared to nanohybrid and micro-hybrid composites after coffee exposure (Beltrami et al. 2018). In nanohybrid composites, the part that separates from the matrix is smaller, making it more resistant to coloration (Cubukcu, Gundogdu & Gul 2023). Additionally, higher filler content improves colour stability (Poggio et al. 2017). Staining is also linked to water absorption by the resin matrix. The degree of water absorption is dependent on both the resin content of the materials and the strength of the resin-filler interface. Excessive water absorption may result in resin expansion and plasticization, causing the formation of microcracks. These interfacial gaps between the fillers and matrix allow stain penetration and subsequent discolouration when filler particles dislodge from the restoration material's surface (Kalita et al. 2023).

All three resin composites were nano-filled, but their colour stability varied due to differences in resin matrix structure, nanofiller size, and composition. This highlights that the heterogeneous nature of composites makes colour stability unpredictable based on composition alone (Kalita et al. 2023). ES exhibited the highest overall colour change over time despite its superior chameleon effect, followed by SS and SL. This suggests ES and SS may be less suitable for highly visible areas such as anterior teeth in patients with strong-pigmented diets. However, SL, with the best colour stability, is better suited for patients prioritizing long-term aesthetic durability.

Post-operative advice on potential colour changes from coffee and turmeric exposure is recommended. Patients should be informed about dietary habits, oral hygiene practice, and regular restorative maintenance for the longevity of the restorations (Laske et al. 2016). Finishing and polishing may improve colour stability by eliminating the outer resin-rich layer, though this effect varies by the type of resin composite (Yew & QamaruzZaman 2012).

The limitations of this research on the chameleon effect and colour stability of nano-filled resin composites are multifaceted. This includes reliance on *in vitro* nature, which may not fully simulate the complexity of the oral cavity, such as the presence of saliva, temperature fluctuations, and dynamic oral tissues that affect the chameleon effect and colour stability (Ismail & Paravina 2021). Limited manufacturer details on material composition such as particle size, filler content, and monomer formulation hinder a comprehensive understanding of their impact on the chameleon effect and colour stability. Therefore, the findings cannot be directly applied to clinical settings and further clinical studies with comprehensive material analyses are needed to validate these results.

The clinical relevance of this study are: I. Chameleon effect: No significant differences between the three resin composites tested - SOLARE Sculpt, Essentia, and SimpliShade, suggests that clinicians can achieve a natural aesthetic outcome using any of these materials as they can adapt to adjacent tooth structures, enabling natural-looking restorations. II. Colour stability: SOLARE Sculpt exhibited superior resistance to staining, with lower colour changes, making it a preferable option for patients who may consume staining foods or beverages. This highlights the importance of selecting the appropriate material based on a patient's dietary habits and the potential for staining. III. While the chameleon effect was similar across materials, SOLARE Sculpt showed the most consistent colour stability over time, especially against common staining agents. Therefore, clinicians may prefer SOLARE Sculpt for restorations in the aesthetic zone, as well as for patients with high aesthetic demands. IV. Clinicians should always advise patients on the importance of good oral hygiene, regular maintenance, and diet to preserve the appearance and longevity of composite resin restorations to ensure long-term aesthetic performance.

CONCLUSIONS

Based on the study results, the null hypothesis that there are no significant differences in the chameleon effect among the three nano-filled composite resins is accepted. However, the null hypothesis that there are no significant differences in the colour stability of the three nano-filled composite resins across different solutions is rejected. SOLARE Sculpt and Essentia demonstrated significant differences in colour stability, with Essentia showing the least overall colour stability. Immersion in solutions such as turmeric and coffee resulted in significant discolouration over time, with turmeric causing the greatest discolouration regardless of the type of resin composite used.

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