Staining of CAD/CAM Composite Materials After Immersion in Coloring Solutions: A Narrative Review

Keywords

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ABSTRACT

Objective: This review integrates published scientific information on the staining potential of CAD/CAM composite materials after immersion in coloring beverages, highlighting the mechanisms of action of these solutions and strategies to minimize staining. Methods: Publications were searched in the PubMed and Scopus databases until April 2025. The search was conducted for publications in English without limits on the year of publication. The MeSH terms, free-text terms, and their combinations used in the databases were: "color", "translucency", "staining", "resin ceramic", "nanoceramic resin," and "hybrid ceramic". Results: The search resulted in 472 articles. After removing duplicate articles, the remaining articles were evaluated in two stages. The selected articles were read in full, and 58 articles were included in this review. Conclusions: Red wine is the beverage that most promotes staining, followed by coffee. Composite materials, especially those containing a hydrophilic resin matrix, are prone to staining over time. Bleaching can be used as an option for stain removal. In turn, periodic polishing of restorations and frequent brushing with toothpaste reduce and prevent staining caused by extrinsic pigments. Clinical Significance: Different beverages consumed by patients can stain resin-based restorative materials. Polishing, bleaching, and brushing can be used to minimize this staining.

INTRODUCTION

CAD/CAM composite materials, also known as resin ceramics, nanoceramics resin, resin-based composites, hybrid composites, hybrid ceramics, nano-hybrid ceramics, or resin matrix ceramics, are materials that combine resins and ceramics in their composition to provide aesthetics, biocompatibility, wear resistance, chemical stability, and machinability in a single material.[1] These hybrid materials are currently used for the manufacture of anterior indirect restorations,[2] inlays/onlays,[3] and implant-supported prosthesis4 due to their efficient laboratory procedures, ease of polishing, and the possibility of clinical repairs.[5]

Composite material blocks are mainly composed of nanometric ceramic fillers (generally silica and/or zirconia) dispersed in a polymeric matrix composed of different monomers.[6] A silane bonding agent is generally responsible for the chemical bond between the ceramic content and the polymeric matrix, and nanofillers of non-aggregated particles and nano-agglomerations present in the composition help reduce the interstitial spaces of the resinous matrix.[7] Industrial polymerization at high temperatures and/or high pressure guarantees a better degree of conversion,[8] a maximization of polymer cross-linking,[7] and superior mechanical properties.[9]

Another CAD/CAM block manufacturing method involves a dual ceramic and polymer structure, in which a porous sintered feldspathic ceramic network (about 80% by weight) is reinforced by an interpenetrated methacrylate polymer network, resulting in a ceramic network infiltrated with polymer.[7,10] These materials exhibit physical properties very close to those of the natural teeth,[11] namely, good wear and fracture resistance.[12]

The color stability of a restorative material increases its longevity, directly impacting the success of aesthetic restorations.[13-17] Unlike ceramic materials, composite materials are prone to changes in their optical properties due to the presence of resin in their composition.[18-20] These changes result from a discoloration/staining process, especially when these materials are exposed to coloring substances present in the oral cavity from food and drinks, smoking habits, and inadequate oral hygiene.[14,21,22] These materials absorb water and extrinsic pigments from coloring agents due to the degradation of their organic matrix.[19,23] The consequent staining becomes a clinical problem for the patient, as its solution often involves replacing stained restorations, inevitably resulting in more tooth wear, increased clinical time, and increased treatment costs.[24]

Factors such as the material composition, type of coloring agent, and time of exposure to the agent influence the degree of staining.[25,26] A long-term clinical investigation found color changes considered acceptable in different CAD/CAM composite materials after 6 and 12 months of clinical service and highlighted that routine toothbrushing might also impact these changes.[27] Because controlling the variables in the oral cavity is difficult, *in vitro* studies are conducted to simulate the staining of aesthetic materials by immersing samples in coloring solutions or by thermal aging in water and/or solution.[28-31] A clinical correspondence of the data obtained by these *in vitro* studies can be made with the perceptibility and acceptability thresholds recommended in the literature.[32,33] This narrative review aims to present structured and updated information about the main staining solutions used by patients, their mechanisms of action, the main results of optical changes reported in the literature for CAD/CAM composite materials, and the strategies suggested to minimize this problem.

METHODS

Publications were electronically searched in the PubMed and Scopus databases until April 2025, using the following MeSH terms, free text terms, and their combinations: “color” OR “translucency” AND “staining” AND “resin ceramic” OR “nanoceramic resin” OR “hybrid ceramic”. The search was conducted for publications written in English without limits on the year of publication. The following inclusion criteria were applied: 1) *in vitro* studies; 2) studies that evaluated optical properties; 3) studies that evaluated staining after immersion in coloring beverages; 4) studies that evaluated CAD/CAM composite materials. The exclusion criteria were as follows: 1) studies that evaluated ceramic materials and direct composite resins; 2) studies that evaluated staining from another staining agent (mouthwashes and tobacco); 3) studies that evaluated other properties (e.g. chemical, mechanical); 4) *in vivo* studies; 5) clinical trials; 6) case reports and case series; 7) literature or systematic reviews; 8) studies published in other languages.

After removing duplicates, two calibrated reviewers (M.G.F.P.M. and L.C.) conducted a two-stage evaluation of the articles’ eligibility. In the first stage, they reviewed the titles and abstracts of the articles and selected those that met the inclusion criteria. In the second stage, they read the full texts of the remaining articles and selected the relevant ones for inclusion. Key information from the included studies was collected, and cross-references of this information were evaluated. Discrepancies between the reviewers and doubts about the collected data were solved in a consensus meeting with the other authors (C.M.F.G.P.A.; P.C.S.V; M.Ö., and C.A.M.V.). Inter-reviewer reliability was assessed using Cohen’s kappa coefficient for the two stages of the eligibility evaluation: the title and abstract review (0.74) and the full-text article review (0.82).

RESULTS

The database search found 472 articles (232 in PubMed and 240 in Scopus). After duplicate article removal (237) and a two-stage evaluation, 58 articles were included in this narrative review *(Figure 1)*.[13-20,22-24,26,28-31,34-75] The selected studies investigated the following CAD/CAM composite materials: Brilliant Crios (Coltene, Switzerland),[22,31,45,71,74,75] Brava Block (FGM, Brazil),[20,62,72] Cerasmart and Cerasmart 300 (GC Corporation, Japan),[14,20,24,26,31,35,42,45,47,52,53,56,58,59,66,68-71,73] Crystal Ultra (Digital Dental, USA),[24,67] Duro Ace (Vericom, Korea),[47] Estelite Block and Estilite P Block (Tokuyama Dental, Japan),[47] Grandio Blocs (VOCO, Germany),[20,29,45,49] Hyramic (Upcera, China),[74] Katana Avencia Block and Katana Avencia P Block (Kuraray, Japan),[47] KZR-CAD HR and KZR-CAD HR3 (Yamakin, Japan),[14,47] Lava Ultimate (3M ESPE, USA),[13-15,17,18,20,22,24,26,28-31,34,35,38-40,42-44,46-48,52,54-56,58,60,67,70,74] Mazic Duro (Vericom,Korea),[47,64] Shofu Block HC (Shofu, Japan),[14,15,22,26,31,45,56,58,74] and Vita Enamic (VITA Zahnfabrik, Germany).[13-16,18,19,22,23,26,30,34-44,46,48-51,54,56-58,60-65,71,74,75] The samples’ thickness ranged from 0.6 to 4.0mm. Table 1 presents the material evaluated, their composition, and their manufacturers.

Coffee was the most used coloring solution for immersion,[13-19,22-24,28-31,35-43,45,46,48,50,52,53,55-61,63-65,68,69-75] followed by red wine,[15,17-19,26,28,37,38,40,42,44,45,47-49,52,56,58,62,65,66,67,70,71,74] tea,[15,17,18,28,29,35,36,38,48,49,51,52,65,71,74] and cola beverages.[15,17,23,29,36,39,40,43,45,49,50,60,63,74] The optical properties of CAD/CAM composite materials were also evaluated after immersion in curry solution,[26,44,49] cress solution,[26,44] ginger,[29,43] energy drink,[45,54] carrot juice,[35,64] grape juice,[57,67] pomegranate juice,[17] and turnip juice.[17] Two studies used combined solutions: a combination of cranberry juice, black tea, and coffee[34] and a staining solution recommended by ADA (coffee, black tea, gastric mucin, FD & C red, FD & C yellow 5, red wine, and distilled water).[20] Table 2 presents the coloring agents used in the studies and the respective methodologies, immersion times/temperatures, and solution renewal.

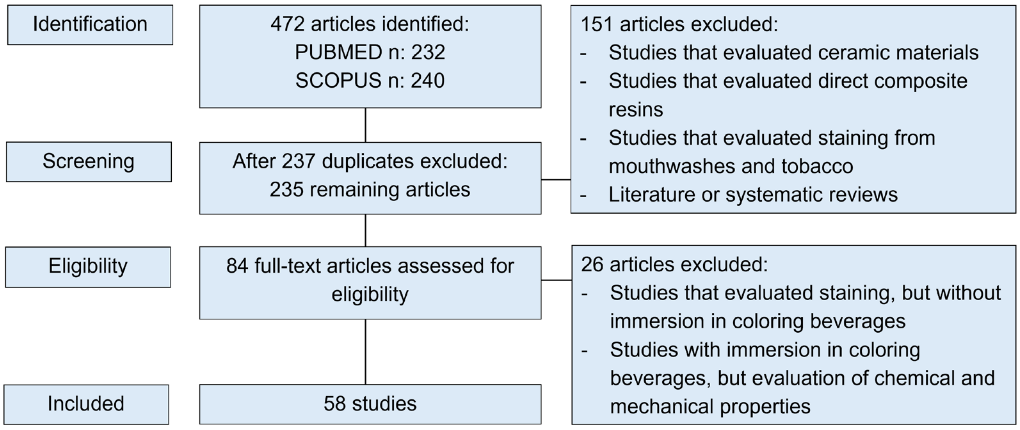


Figure 1: Flow diagram with information about the article selection.

Several optical properties were evaluated using different formulas, including for the same property: color differences (ΔE_{ab}) evaluated by CIELAB;[14-16,18,23,26,35,36,39,40,41,43,44,47,48,50,51,53,60,64,65,67] color differences (ΔE_{00}) evaluated by CIE DE2000:[13,17,19,20,22,24,28,29,31,34,42,45,49,54-56,59,61-63,67-69,70,72-75] lightness (ΔL'), chroma (ΔC'), and hue (ΔH') differences evaluated by CIEDE 2000;[63,72] translucency parameter (TP_{ab}) evaluated by CIELab;[20,22,24,39,47,55] translucency parameter (TP_{00}) evaluated by CIEDE2000;[58,72] translucency parameter differences differences (ΔTP_{ab});[14,15,22,29,37,42,43,63] ΔTP_{00};[59,62,70,72-74] contrast ratio (CR) evaluated by CIEXYZ;[42] contrast ratio differences (ΔCR);[42] gloss;[20,34] whiteness index (WI_D);[22,29,55] whiteness index differences (ΔWI_D),[22] and fluorescence differences (ΔF).[20] Table 3 describes 50 of the included studies, including the materials evaluated, the number and size of samples, and results found for the optical properties mentioned above. The remaining 8 articles are not in this table because they only presented graphical results.[24,30,35,38,46,57,71,52]

The included studies show no methodological standardization regarding the immersion times and agents used. No correlation was found between the time of sample immersion in a beverage and the corresponding beverage consumption. On the other hand, there is a consensus that CAD/CAM composite materials' susceptibility to staining depends on the coloring agent and immersion time used.[13-20,22-24,34-75] Although most studies described the preparation of the solutions, the temperature, and the time used to immerse the samples, some studies did not describe these data in detail in the methodology, impacting their reliability.[13,15,23,28,41,57,61-64,66]

STAINING AFTER IMMERSION IN COFFEE

Coffee is composed of organic acids (chlorogenic and caffeic acids), polyphenols (such as tannins), and natural pigments (such as melanin). Condensed-type primary tannins (also known as proanthocyanidins) are mainly responsible for the coffee's characteristic color.[76,77] Tannins tend to easily bind to proteins through hydrogen bonds or hydrophobic interactions.[78] The mechanism behind this interaction can involve molecular adhesion or absorption since tannins can penetrate the materials (especially those that are more porous or undergoing degradation). These natural pigments with high molecular weight and low polarity have a great affinity for the polymer matrix of composite materials, resulting in staining over time.[38,56,72]

Variations in immersion times and staining protocols are frequent in the literature. These protocols must be carefully observed because the immersion time, concentration, and temperature of the coloration solution can directly influence the degree of staining in the material.[28,39,66] In the selected studies that evaluated the optical properties of composite materials, the coffee immersion time varied between 24 hours,[14,19,35,42,45,46,52] 60 hours,[58] 90 hours,[55,73] 120 hours,[58] 7 days,[14,15,17,19,22,28,29,31,35,45,46,52,53,59,63,68,70,73] 14-15 days,[16,17,28,40,41,46,60,61,63,73] 21 days,[23,28] 28-30 days,[14,16,17,19,24,28,35-37,42,43,45,46,48,50,52,63,64,70,71,73] 84 days,[16] and 120 days.[18,38,48,56] Immersion was performed at room temperature (37°C), with regular changes of the solution (ranging from every 8 hours to every 12 days) to avoid bacterial contamination. Coffee immersion was combined with thermocycling,[13,17,24,30,31,46,49,51,68,69,75] simultaneously[13,30,51,69,75] or before or after thermocycling.[17,24,31,46,49,68] Coffee-tea, coffee-cola, coffee-wine, coffee-pomegranate juice, and coffee-turnip juice combinations were evaluated to simulate an *in vitro* condition closer to reality since patients consume different beverages.[17]

Furthermore, the literature shows concern about the correlation between results obtained after *in vitro* immersion and the in vivo condition. Studies suggest that 24 hours of immersion in coffee would simulate approximately 30 days of regular consumption.[79,80] Individuals who regularly drink coffee ingest approximately 3.2 cups daily, with each cup being drunk in 15 minutes, totaling 48 minutes per day.[81] A study evaluated the color and translucency of a composite material after immersion in coffee by simulating the consumption once a day (15 min of immersion) and throughout 1 day (48 min), 1 week (336 min), 1 month (1440 min), 6 months (8640 min), and 2 years (35,040 min); it noted progressive changes in these properties over time.[72]

The included studies found color changes after coffee immersion at all times evaluated, with ΔE_{ab} values from 0.4 (for Vita Enamic after 72 hours of immersion)[65] to 14.2 (for Lava Ultimate after 120 days of immersion)[48] and ΔE_{00} from 0.4 (for

Table 1. Materials included in this study and their composition and manufacturer.

Material	Composition	Manufacturer
Brilliant Crios	70 wt% barium glass and amorphous silica, 30 wt% cross-linked methacrylates (Bis-GMA, Bis-EMA, TEGDMA)	Coltene, Switzerland
Brava Block	65 to 80 wt% barium glass, 20 to 30 wt% Bis-EMA, Bis-GMA, dimethylaminobenzoate, coiniciator, camphorquinone	FGM, Brazil
Cerasmart	71 wt% nanoceramic fillers (silica and barium glass), 29 wt% acrylate polymer networks (Bis-MEPP, UDMA, DMA)	GC Corporation, Japan
Cerasmart 300	78 wt% nanoceramic fillers (silica and barium glass), 22 wt% acrylate polymer networks (Bis-MEPP, UDMA)	GC Corporation, Japan
Crystal Ultra	70 wt% ceramic-like inorganic silicate glass fillers, 30 wt% cross-linked polymers (Bis-GMA, UDMA, BUDMA)	Digital Dental, USA
Duro Ace	85 wt% silica, Ba-glass, 15 wt% UDMA, Bis-EMA	Vericom, Korea
Estelite Block	75 wt% silica, silica-zirconia, 25 wt% UDMA, TEGDMA	Tokuyama Dental, Japan
Estelite P Block	81 wt% silica, silica-zirconia, 19 wt% Bis-MPEPP, UDMA, NPGDMA	Tokuyama Dental, Japan
Grandio Blocs	86 wt% nano-hybrid filler, 14 wt % UDMA, DMA	VOCO, Germany
Hyramic	55 to 85 wt% barium glass, silicon dioxide, UDMA, TEGDMA	Upcera, China
Katana Avencia Block	38 wt% silica, alumina filler, 62 wt% UDMA, TEGDMA	Kuraray, Japan
Katana Avencia P Block	18 wt% Ba-glass, silica, 82 wt% UDMA	Kuraray, Japan
KZR-CAD HR	79 wt% SiO_2, Al_2O_3, ZrO_2,SiO_2, 21 wt% UDMA, TEGDMA	Yamakin, Japan
KZR-CAD HR3	75 wt% SiO_2, Al_2O_3, ZrO_2,SiO_2, 25 wt% UDMA, DEGDMA	Yamakin, Japan
Lava Ultimate	80 wt% SiO_2, ZrO_2, aggregated ZrO_2/SiO_2 microcluster, 20 wt % Bis-GMA, UDMA, Bis-EMA, TEGDMA (20 wt%)	3M ESPE, USA
Mazic Duro	77 wt% barium aluminosilicate, silicon dioxide, and zirconia, 23 wt% UDMA, TEGDMA	Vericom, Korea
Shofu Block HC	61 wt% silica-based glass and silica, 39 wt% UDMA, TEGDMA	Shofu, Japan
Vita Enamic	86 wt% feldspathic ceramic enriched with aluminum oxide, 14 wt% cross-linked polymers (Bis-GMA, UDMA)	VITA Zahnfabrik, Germany

***Bis-EMA: ethoxylated bisphenol A dimethacrylate; Bis-GMA: bisphenol A diglycidylether methacrylate; Bis-MEPP: 2,2-bis(4-methacryloxypolyethoxyphenyl) propane; BUDMA: 1,4-Butanediol dimethacrylate; DMA: dimethacrylate; DMA: N,N-Dimethylacetamide; NPGDMA: neopentyl glycol dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate.**

Vita Enamic after 1 week of immersion and Lava Ultimate after 3 days of immersion)[22,74] to 14.2 (Lava Ultimate after 4 weeks of immersion).[28] Increasing immersion times were associated with more pronounced color differences.[56,72] Two studies evaluated lightness, chroma, and hue differences, reporting reduced lightness, yellowing, and reddishness of the samples after immersion in coffee.[63,72]

The most studied materials were Vita Enamic and Lava Ultimate (*Table 3*). Figures 2 (A and B) and 3 (A and B) show the ΔE_{ab} and ΔE_{00} values found in the included articles that assessed these materials. The studies reported the color difference values after immersion in coffee, not including any additional treatment (such as polishing, glazing, brushing, or bleaching). Those graphs also depict a comparison with the perceptibility (PT) and acceptability (AT) thresholds, according to the formula that was used in the analysis of the L*a*b*

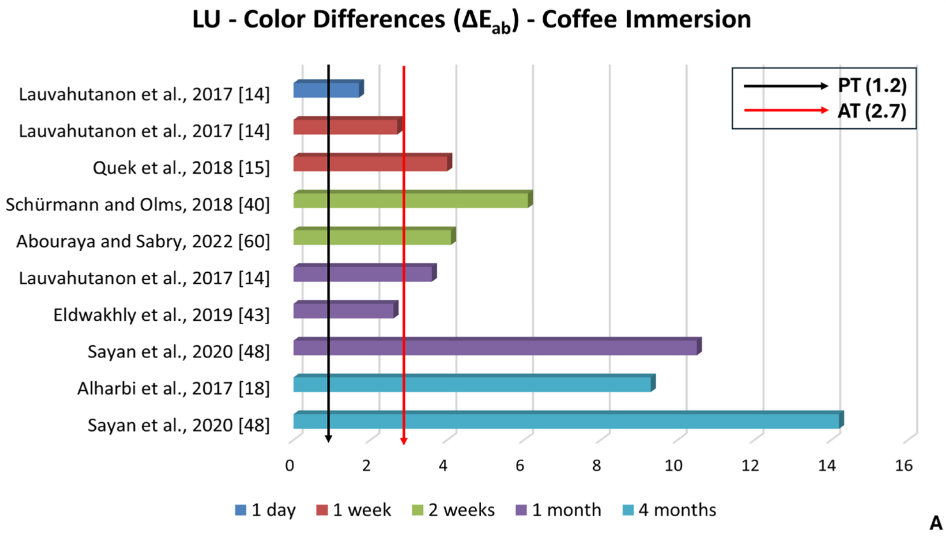
Table 2. Coloring solutions, preparation described in the methodology, immersion time and temperature, and solution renewal frequency.

	Coloring Solutions								
Study	Coffee	Wine	Tea	Cola	Others	Preparation - methodology	Immersion time	Immersion temperature	Renewal of solutions
Arocha et al., 2014[28]	Nescafé Classic (Nestlé, Switzerland)	Tempranill Cavernet Sauvignon (Spain)	Lipton Tea, (Unilever, France)	-	-	- Did not mention	1, 2, 3, and 4 weeks	37 °C	Every 2 days
Stawarczyk et al., 2015[26]	-	La Tendo Rioja (Spain)	-	-	Cress solution and Curry solution (Ostmann, Germany)	- Tamped fresh cress boiled in 1 L of water for 10 min. - Curry powder boiled in 1 L of water for 10 min.	14 days	37 °C	Did not mention
Acar et al., 2016[13]	Did not mention	-	-	-	-	- Tablespoon of coffee for 177 mL of water.	Thermal cycling (5,000 cycles)	5–55 °C	Every 8 hours
Lawson & Burgess, 2016[34]	-	-	-	-	Staining solution (Cranberry juice, black tea, and coffee)	- 600 mL of cranberry juice, 3 black tea bags, and 50 mL of instant coffee.	12 days	37 °C	Did not mention
Sagsoz et al., 2016[35]	Did not mention	-	Did not mention	-	Carrot juice	- Did not mention	1 day, 1 week, 1 month	37 °C	Every 3 days
Sayed et al., 2016[36]	Did not mention	-	Did not mention	Coca-Cola (Coca-Cola Company, USA)	-	- Coffee powder added to boiling distilled water. - Immersion of a tea bag in boiling distilled water 5 times. - Immersion in 4 ˚C cold Coca-Cola.	10 min twice daily for 30 days	37 °C	Renewed after each application
Alharbi et al., 2017[18]	Arpeggio (Nespresso, Switzerland)	Côtes du Rhône (France)	Classic Earl Grey Tea (Twinings Company, England)	-	-	- 1.5 mL of coffee solution. - 1.5 mL of red wine. - 1.5 mL of a tea solution.	120 days	37 °C	Every 12 days
Lauvahutanon et al., 2017[14]	Nescafé Gold Blend (Nestlé, Switzerland)	-	-	-	-	- Instant coffee powder into 50 mL of deionized water.	1 day, 1 week, and 1 month	37 °C	Every day
Saba et al., 2017[37]	Nescafé Classic (Nestlé, Switzerland)	Omar El Khayam (Egypt)	-	-	-	- Coffee powder added to 10 mL of distilled water. - Immersion in 5 mL of each solution.	28 days	37 °C	Every 2 days
Alharbi et al., 2018[38]	Arpeggio (Nespresso, Switzerland)	Côtes du Rhône (France)	Classic Earl Grey Tea (Twining, England)	-	-	- 1.5 mL of coffee solution. - 1.5 mL of red wine. - 1.5 mL of a tea solution.	120 days	37 °C	Every 12 days
Özarslan et al., 2018[19]	Nescafé (Nestlé, Switzerland)	Doluca (Turkey)	-	-	-	- Coffee powder added to 500 mL of boiling distilled water.	24 h, 7 and 28 days	37 °C	Every day
Quek et al., 2018[15]	Did not mention	Did not mention	Did not mention	Did not mention	-	- Immersion in 200 mL of each solution.	7 days	37 °C	Every 2 days
Sarıkaya et al., 2018[39]	Nescafé Classic (Nestlé, Switzerland)	-	-	Coca-Cola (Coca-Cola Company, USA)	-	- Coffee powder added to 300 mL of boiling water. - Immersion in 330 mL of Coca-Cola.	48 hours	37 °C	Did not mention
Schürmann & Olms, 2018[40]	Nescafé (Nestlé Switzerland)	Blauer Zweigelt (Germany)	-	Coca-Cola (Coca-Cola Company, USA)	-	- Coffee powder added to 100 mL of distilled water.	14 days	37 °C	Every 3.5 days
Tannir et al., 2018[41]	Did not mention	-	-	-	-	- Did not mention	15 days	Did not mention	Did not mention
Arif et al., 2019[30]	Black Silk (The Folger Coffee, USA)	-	-	-	-	- Coffee powder added to 15 mL of water.	Thermal cycling (6,000 cycles)	5–55 °C	Every 8 hours
Barutçugil et al., 2019[42]	Nescafé Classic (Nestlé, Switzerland)	Doluca Öküzgözü, (Turkey)	-	-	-	- Sachet dissolved into 200 mL of boiling water with no sugar or milk.	24 hours and 30 days	37 °C	Every day
Eldwakhly et al., 2019[43]	Nescafé Classic (Nestlé, Switzerland)	-	-	Coca-Cola (Coca-Cola Company, USA)	Ginger (Royal Herbs, Egypt)	- Coffee powder added to 1 L of boiling distilled water. - Ginger added to 1 L of boiling distilled water.	28 days	37 °C	Every day
Gasparik et al., 2019[22]	Nescafé Brasero (Nestlé, Switzerland)	-	-	-	-	- Immersion in 3 ml of coffee solution for each sample.	1 week	37 °C	Every day
Liebermann et al., 2019[44]	-	La Tendo Rioja (Spain)	-	-	Cress solution and Curry solution (Ostmann, Germany)	- Tamped fresh cress boiled in 1 L of water for 10 min. - Curry powder boiled in 1 L of water for 10 min.	1 and 7 days	37 °C and 55 °C	Not changed
Aydin et al., 2020[45]	Nescafé Classic (Nestlé, Switzerland)	Kalecik Black (Turkey)	-	Coca-Cola (Coca-Cola Company, USA)	Energy drink (Red Bull, Austria)	- Coffee powder added to 200 mL of boiling distilled water.	1, 7, and 30 days	37 °C	Every 24 hours
Bahadir & Bayraktar, 2020[46]	Nescafé (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 200 mL of hot water.	Thermal cycling (10,000 cycles) before immersion for 1, 7, 14, and 28 days	5–55 °C 37 °C	Every day
Kang et al., 2020[47]	-	Simulated red wine (China)	-	-	-	- Kuromanin chloride and red pigment were poured into 500 mL of 10% ethanol solution.	1, 2, 4, 6, 8, and 12 weeks	37 °C	Every day
Sayan et al., 2020[48]	Nescafé Classic (Nestlé, Switzerland)	Buzbağ klasik Elazığ-Diyarbakır (Turkey)	Lipton Yellow Tea, (Unilever, France)	-	-	- 5 mL of coffee, red wine, and tea. - Instant coffee was added to 200 mL of water at 100 °C. - A tea bag placed into 200 mL of water at 100 °C.	30 and 120 days	37 °C	Every 10 days
Seyidaliyeva et al., 2020[49]	-	Did not mention	Did not mention	Did not mention	Curry solution	- Immersion in 60 mL staining solution. - 3 tea bags into 60 mL of water. - Curry into 60 mL of water.	Thermal cycling (10,000 cycles) before immersion for 4 weeks	6.5-60 °C 37 °C	Every 2 days
Younis et al., 2020[50]	Nescafé soluble coffee (Nestlé, Switzerland)	-	-	Coca-Cola (Coca-Cola Company, USA)	-	- Coffee powder added to boiling water. - 50 ml of Coca-Cola.	28 days	37 °C	Every day
Adawi et al., 2021[16]	Arabic Qahwa (Baja, Saudi Arabia) Frappuccino cold coffee (Starbucks, USA)	-	-	-	-	- Instant coffee into 1 L of boiling water. - Frappuccino Cold Coffee was readily available in a sealed bottle to be shaken well and used.	2, 4, and 12 weeks	37 °C	Every 24 hours
Al Amri et al., 2021[24]	Nescafé Classic (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 250 mL of hot water.	Thermal cycling (5,000 cycles) before and after immersion for 7 days	5–55 °C 37 °C	Every day
Aldosari et al., 2021[51]	Frappuccino cold coffee (Starbucks, USA) Arabic Qahwa (Baja, Saudi Arabia)	-	-	-	-	- Instant coffee into 1 L of boiling water. - Frappuccino Cold Coffee was readily available in a sealed bottle to be shaken well and used.	Thermal cycling (5,000 cycles)	37 °C	Every day
Koçak et al., 2021[52]	Nescafé Classic (Nestlé, Switzerland)	Yakut Kavaklıdere (Turkey)	Lipton Yellow Tea (Unilever, France)	-	-	- Coffee added to 200 mL of boiling water. - Tea in 150 mL of boiling water for 5 min.	1, 7, and 30 days	37 °C	Every day
Sağlam et al., 2021[53]	Nescafé Classic (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 300 mL of boiling water.	7 days	37 °C	Every day
Sarıkaya & Dilli 2021[54]	Nescafé Classic (Nestlé, Switzerland)	-	-	-	Energy drink (Red Bull, Austria)	- Coffee powder was added, and the solution was filtered through filter paper after stirring for 10 s. - Immersion in 250 mL of energy drink.	48 hours	37 °C	Every 8 hours
Silva et al., 2021[55]	Nescafé Tradition (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 100 mL of boiling distilled water.	3 hours	37 °C	-
Stamenkovic et al., 2021[56]	Folgers Classic Roast Medium (The Folger Coffee, USA)	Cabernet Sauvignon Frontera Concha y Toro (Chile)	-	-	-	- Coffee added to 600 mL of boiling water.	60 and 120 days	37 °C	Every day
Sulaiman et al., 2021[57]	Did not mention	-	-	-	Grape juice	- Did not mention	14 days	37 °C	Did not mention
Tango et al., 2021[58]	Folgers Classic Roast Medium (The Folger Coffee, USA)	Cabernet Sauvignon Frontera Concha y Toro (Chile)	-	-	-	- Coffee added to 600 mL of boiling water.	60 and 120 hours	37 °C	Every day
Yildirim & Recen, 2021[59]	Nescafé Gold (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 500 mL of hot water.	1 week	37 °C	Every day
Abouraya & Sabry, 2022[60]	Nescafé Classic (Nestlé, Switzerland)	-	-	Pepsi Cola (PepsiCo, USA)		- Coffee powder added to 1 L of boiling distilled water.	2 weeks	37 °C	Every 3 days
Al Ahmari et al., 2022[61]	Starbucks, (USA)	-	-	-	-	- Did not mention	15 and 30 days	37 °C	Twice per day
Alsilani et al., 2022[23]	Nescafé Gold (Nestlé, Switzerland)	-	-	Coca-Cola (Coca-Cola Company, USA)	-	- Did not mention	3 weeks	37 °C	Every day
Andrade et al., 2022[20]	-	-	-	-	Staining broth (American Dental Association)	- This broth was prepared with instant coffee (Nescafé Classic; Nestlé, Switzerland), black tea (Leão; Coca-Cola Company, USA), gastric mucin (Inlab; Brazil), FD & C red (Cosmoquímica; Brazil), FD & C yellow 5 red (Cosmoquímica; Brazil), red wine (Santa Helena, Chile), and distilled water.	15 days	37 °C	Every day
Dalforno et al., 2022[62]	-	Salton Classic Cabernet Sauvignon (Brazil)	-	-	-	- Did not mention	30 hours in 15 and 30 days	37 °C	Every day
Elsaka et al., 2022[29]	Nescafé Classic (Nestlé, Switzerland)	-	Twinings (Twinings Company, England)	Coca-Cola (Coca-Cola Company, USA)	Ginger (Royal Herbs, Egypt)	- Coffee powder added to 300 mL of boiling distilled water. - Teabags into 300 mL of boiling distilled water for 10 min. - Ginger packets into 300 mL of boiling distilled water for 10 min.	7 days	37 °C	Every 2 days
Intralawan et al., 2022[63]	Nescafé (Nestlé, Switzerland)	-	-	Coca-Cola (Coca-Cola Company, USA)	-	- Did not mention	1 and 2 weeks, 1 month	37 °C	Every day
Jalali et al., 2022[64]	Did not mention	-	-	-	Carrot juice	- Did not mention	1 month	37 °C	Every 3 days
Qaraghuli et al., 2022[65]	Illy Caffe (Italy)	I Somelieri Freisa Monferrato (Italy)	Ahmad Tea London (United Kingdom)	-	-	- Coffee powder added to 600 mL of boiling distilled water. - Tea into 1 L of boiling water and brewed on a quiet fire for 4-5 min.	72 hours	37 °C	Did not mention
Ugurlu, 2022[66]	-	Did not mention	-	-	-	- Did not mention	15 days	37 °C	Every day
Yerliyurt & Sarıkaya, 2022[17]	Nescafé Classic (Nestlé, Switzerland)	Mediterranean Pearl (Turkey)	Lipton (Unilever, France)	Coca-Cola (Coca-Cola Company, USA)	Pomegranate juice Turnip juice (Dimes Food Co., Turkey)	- Coffee powder added to 500 mL of boiling distilled water. - Tea bag into 150 mL of boiling water for 5 min. - 250 mL of pomegranate juice was obtained from 1 kg of pomegranate.	Thermal cycling (10,000 cycles) before immersion for 1, 7, 14, and 28 days	37 °C	Every 12 hours
Ashtiani et al., 2023[67]	-	-	Shahrzad (Iran)	-	Grape juice (Sunich, Iran)	- Tea powder added to 200 mL of boiling distilled water.	30 days	37 °C	Every 24 hours
Bozogullari & Temizci, 2023[68]	Nescafé Gold (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 300 mL of boiling distilled water.	Thermal cycling (5,000 cycles) before immersion for 7 days	5–55 °C 37 °C	Every day
Bayraktar et al., 2024[31]	Nescafé Gold (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 100 mL of distilled water.	Thermal cycling (1,500 cycles) before immersion for 7 days	5–55 °C 37 °C	Every day
Çakmak et al., 2024[69]	Kaffeehof (Germany)	-	-	-	-	- Coffee powder added to 177 mL of water.	Thermal cycling (5,000 cycles)	5–55 °C	Every 12 hours
Bek Kurklu & Sonkaya, 2024[70]	Nescafé Classic (Nestlé, Switzerland)	Buzba Közgözü-Boğazkere (Turkey)	-	-	-	- Coffee powder added to 200 mL of heated water without any added sugar or milk.	24 hours, 7 and 30 days	37 °C	Every day
Naffah et al., 2024[71]	Nescafé Red (Nestlé, Switzerland)	Clos St-Thomas, Lebanon	Lipton (Unilever, France)	-	-	- Coffee powder added to 500 mL water. - 500 ml of red wine. - Tea bags put into 500 mL of water.	30 days	37 °C	Every 8 hours
Schneider et al., 2024[72]	Nescafé Original Extraforte (Nestlé, Switzerland)	-	-	-	-	- Coffee powder added to 100 mL of boiling water.	15, 48, 336, 1440, 8640, and 35,040 min	37 °C	Every 24 hours
Krajangta et al., 2024[73]	Nescafé House Blend Ready-to-Drink (Nestlé, Switzerland)	-	-	-	-	- Did not mention	30 days	37 °C	Every day
Zhang et al., 2024[74]	Nescafé Classic (Nestlé, Switzerland)	Greatwall Cabernet, Cofco	Yellow Label Tea, Lipton (Unilever, France)	Coca-Cola (Coca-Cola Company, USA)	-	- Coffee powder added to 150 mL of boiled distilled water. - Tea bag into 250 mL of boiling distilled water. - Did not mention (coca-cola and wine)	3, 7, and 14 days	37 °C	Every day
Çakmak et al., 2025[75]	Kaffeehof (Germany)	-	-	-	-	- Coffee dissolved in 177 mL of water.	Thermal cycling (10,000 cycles)	5–55 °C	Every 12 hours

Table 3. Main studies and data on the optical properties of CAD/CAM resin-ceramic materials after immersion in coloring solutions.

Study	Materials	Samples	Color differences (ΔE_{ab} and ΔE_{00})	Translucency parameter (TP_{ab} and TP_{00}) and translucency parameter differences (ΔTP_{ab} and ΔTP_{00})	Other optical properties
Arocha et al., 2014[28]	- Lava Ultimate (A2-LT)	- n: 40 - Ø 10-mm, 2-mm thick	- ΔE_{00} for coffee: LU: 10.9 to 14.2 - ΔE_{00} for wine: LU: 19.9 to 31.9 - ΔE_{00} for tea: LU: 6.9 to 11.0	-	-
Stawarczyk et al., 2015[26]	- Cerasmart (A2-HT) - Lava Ultimate (A2-HT) - Shofu Block HC (A2-HT) - Vita Enamic (2M2-HT)	- n: 12 each - 14 x 12 x 1 mm	- ΔE_{ab} for wine: CE: 19.7; LU: 15.1; SB: 18.6; VE: 13.6 - ΔE_{ab} for cress solution: CE: 1.4; LU: 3.3; SB: 2.2; VE: 4.3 - ΔE_{ab} for curry solution: CE: 6.5; LU: 7.8; SB: 8.7; VE: 5.4	-	-
Acar et al., 2016[13]	- Lava Ultimate (A1-LT) - Vita Enamic (1M2-HT)	- n: 5 each - 0.5 to 0.7-mm and 1 to 1.2-mm thick	- ΔE_{00} for coffee: LU: 2.2; VE: 1.3 - 2.2	-	
Lawson & Burgess, 2016[34]	- Lava Ultimate (A1-LT) - Vita Enamic (OM1-T)	- n: 16 each - 4-mm thick	- ΔE_{00} for staining solution: LU Un-pol: 2.7; LU Pol: 1.5; VE un-pol: 1.2; VE pol: 0.8	-	- GU for staining solution: LU Un-pol: 30.5; LU pol: 85.4; VE un-pol:12.3; VE pol: 70.7
Sayed et al., 2016[36]	- Vita Enamic	- n: 15 - 0.7 labially and 1.5-mm incisally thick	- ΔE_{ab} for coffee: 9.6 - ΔE_{ab} for tea: 7.8 - ΔE_{ab} for cola: 6.5	-	-
Alharbi et al., 2017[18]	- Lava Ultimate (A3) - Vita Enamic (A3)	- n: 40 each - 10 x 1 mm	- ΔE_{ab} for coffee: LU: 9.3; VE: 4.2 - ΔE_{ab} for wine: LU: 15.3; VE: 14.3 - ΔE_{ab} for tea: LU: 7.8; VE: 8.4	-	-
Lauvahutanon et al., 2017[14]	- Cerasmart (A3-LT) - KZR-CAD HR - Lava Ultimate (A3-HT) - Shofu Block HC (A3-HT) - Vita Enamic (3M2-HT)	- n: 12 each - Ø 10 mm; 2-mm thick	- ΔE_{ab} for coffee: CE: 1.2 (1 day), 1.9 (1 week), 2.7 (1 month); KZR: 1.0 (1day), 1.6 (1 week), 2.9 (1 month); LU: 1.7 (1day), 2.7 (1 week), 3.6 (1 month); SB: 1.3 (1day), 2.2 (1 week), 3.7 (1 month); VE: 0.5 (1day), 0.8 (1 week), 1.4 (1 month)	- ΔTP_{ab} for coffee: CE: -0.2 (1day), -0.3 (1 week), -0.4 (1 month); KZR: -0.8 (1day), -1.4 (1 week), -1.8 (1 month); LU: -0.4 (1day), -0.7 (1 week), -1.2 (1 month); SB: -0.3 (1day), -0.6 (1 week), -1.0 (1 month); VE: -0.1 (1day), -0.3 (1 week), -0.7 (1 month)	-
Saba et al., 2017[37]	- Vita Enamic	- n: 18 - 14 x 12 x 2 mm	- ΔE_{ab} for coffee: 4.9 - ΔE_{ab} for wine: 0.7	-	-
Özarslan et al., 2018[19]	- Vita Enamic (HT and T)	- n: 90 (each) - 12 x 14 x 2 mm	- ΔE_{00} for coffee: VE - HT: 1.8 (24h), 3.7 (7 days), 4.1 (28 days); VE - T: 1.3 (24h), 5.1 (7 days), 5.5 (28 days). - ΔE_{00} for wine: VE - HT: 2.8 (24h), 3.4 (7 days), 7.1 (28 days); VE - T: 2.8 (24h), 2.0 (7 days), 5.3 (28 days)	-	-
Quek et al., 2018[15]	- Lava Ultimate (A2-HT) - Shofu Block HC (A2-HT) - Vita Enamic (2M2-HT)	- n: 40 each - 12 x 14 x 1.5 mm	- ΔE_{ab} for coffee: LU: 4.0; SB: 4.1; VE: 4.1 - ΔE_{ab} for wine: LU: 6.3; SB: 5.6; VE: 6.2 - ΔE_{ab} for tea: LU: 3.2; SB: 5.4; VE: 5.4 - ΔE_{ab} for cola: LU: 0.6; SB: 0.7; VE: 1.2	- ΔTP_{ab} for coffee: LU: -1.2; SB: -1.6; VE: -1.7 - ΔTP_{ab} for wine: LU: -3.0; SB: -2.8; VE: -3.3 - ΔTP_{ab} for tea: LU: -1.9; SB: -2.5; VE: -1.9 - ΔTP_{ab} for cola: LU: -0.1; SB: -0.2; VE: -0.3	-
Sarıkaya et al., 2018[39]	- Lava Ultimate - Vita Enamic	- n: 36 each - 12 x 15 x 1 mm	- ΔE_{ab} for coffee: LU: 3.4 to 3.9; VE: 3.2 to 3.6 - ΔE_{ab} for tea: LU: 2.7 to 3.6; VE: 2.6 to 2.9 - ΔE_{ab} for cola: LU: 1.9 to 2.8; VE: 1.8 to 2.5	- TP_{ab} for coffee: LU: 16.2 to 18.1; VE: 14.1 to 15.4 - TP_{ab} for tea: LU: 18.3 to 20.0; VE: 16.4 to 18.0 - TP_{ab} for cola: LU: 18.5 to 19.8; VE: 16.2 to 18.0	-
Schürmann & Olms, 2018[40]	- Lava Ultimate - Vita Enamic	- n: 20 each - 2-mm thick	- ΔE_{ab} for coffee: LU: 6.1; VE: 3.6 - ΔE_{ab} for wine: LU: 8.6; VE: 6.0Δ - ΔE_{ab} for cola: LU: 1.3; VE: 1.8	-	-
Tannir et al., 2018[41]	- Vita Enamic	- n: 10 - Incisal=1.5 mm - Labial=0.6 mm	- ΔE_{ab} for coffee: 4.1	-	-
Barutçugil et al., 2019[42]	- Cerasmart (A2-HT) - Lava Ultimate (A2-LT) - Vita Enamic (2M2-HT)	- n: 45 each - 1.5-mm thick	- ΔE_{00} for coffee: CE: 2.3 (24h) and 3.1 (30 days); LU: 2.1 (24h) and 3.2 (30 days); VE: 2.2 (24h) and 3.6ΔE00 (30 days) - ΔE_{00} for wine: CE: 1.1 (24h) and 2.7 (30 days); LU: 1.6 (24h) and 3.5 (30 days); VE: 1.6 (24h) and 2.9 (30 days)	- ΔTP_{ab} for coffee: CE: -1.1 (24h) and -1.1 (30 days); LU: -0.2 (24h) and -0.7 (30 days); VE: -0.1 (24h) and -0.7 (30 days) - ΔTP_{ab} for wine: CE: -0.7 (24h) and -1.4 (30 days); LU: -0.3 (24h) and -1.6 (30 days); VE: -0.1 (24h) and -0.8 (30 days)	- CR for coffee: CE: 0.04 (24h) and 0.037 (30 days); LU: 0.02 (24h) and 0.04 (30 days); VE: 0.01 (24h) and 0.03 (30 days) - CR for wine: CE: 0.01 (24h) and 0.02 (30 days); LU: 0.01 (24h) and 0.03 (30 days); VE: 0.001 (24h) and 0.01 (30 days)
Eldwakhly et al., 2019[43]	- Lava Ultimate (A2-LT) - Vita Enamic (2M2-T)	- n: 32 each - Ø 10 mm; 2-mm thick	- ΔE_{ab} for coffee: LU: 2.6; VE: 1.6 - ΔE_{ab} for cola: LU: 1.7; VE: 0.9 - ΔE_{ab} for ginger: LU: 1.3; VE: 2.2	- ΔTP_{ab} for coffee: LU: -1.0; VE: -1.4 - ΔTP_{ab} for cola: LU: -0.6; VE: -0.6 - ΔTP_{ab} for ginger: LU: -2.0; VE: -1.4	-
Gasparik et al., 2019[22]	- Brilliant Crios (A3-HT and LT) - Lava Ultimate (A3-HT and LT) - Shofu Block HC (A3-HT and LT) - Vita Enamic (3M2-HT and T)	- n=5 each - 1-mm thick	- ΔE_{00} for coffee: BC: 2.3 (HT) and 1.5 (LT); LU: 3.1 (HT) and 2.0 (LT); SB: 1.8 (HT) and 1.2 (LT); VE: 0.5 (HT) and 0.4ΔE_{00} (T)	- TP_{ab} for coffee: BC: 21.8 (HT) and 19.9 (LT); LU: 21.9 (HT) and 21.2 (LT); SB: 23.0 (HT) and 21.7 (LT); VE: 18.8 (HT) and 16.4 (T) - ΔTP_{ab} for coffee: BC: -1.0 (HT) and -0.4 (LT); LU: -0.6 (HT) and -0.2 (LT); SB: -0.4 (HT) and -0.1 (LT); VE: -0.1 (HT) and -0.1 (T)	- WI_D for coffee: BC: 24.7 (HT) and 0.8 (LT); LU: 29.0 (HT) and 18.7 (LT); SB: 27.3 (HT) and 15.8 (LT); VE: 9.2 (HT) and -9.4 (T) - ΔWI_D for coffee: BC: -6.4 (HT) and -5.4 (LT); LU: -8.1 (HT) and -6.6 (LT); SB: -4.6 (HT) and -4.1 (LT); VE: -1.5 (HT) and -1.7 (T)
Liebermann et al., 2019[44]	- Lava Ultimate (A2-HT) - Vita Enamic (M2-T)	- n: 96 each - 1-mm thick	- ΔE_{ab} for wine: LU: 0.6 - 1.8 (37°C) and 1.7 - 8.4 (55°C); VE: 0.7 -1.0 (37°C) and 1.3 - 4.6 (55°C) - ΔE_{ab} for cress solution: LU: 2.1 - 4.6 (37°C) and 5.0 - 4.5 (55°C); VE: 4.3 -2.7 (37°C) and 3.7 - 4.3 (55°C) - ΔE_{ab} for curry solution: LU: 4.8 - 6.4 (37°C) and 7.8 - 12.5 (55°C); VE: 5.4 - 4.8 (37°C) and 3.7 - 4.3 (55°C)	-	-
Aydin et al., 2020[45]	- Brilliant Crios - Cerasmat - Grandio Blocs - Shofu Block HC	- n: 40 each - 7 x 12 x 1.5 mm	- ΔE_{00} for coffee: BC: 1.5 (1 day), 1.9 (7 days), and 2.9 (30 days); CE: 1.1 (1 day), 1.2 (7 days), and 2.3 (30 days); GB: 1.9 (1 day), 1.3 (7 days), and 2.4 (30 days); SB: 1.4 (1 day), 2.1 (7 days), and 2.4 (30 days) - ΔE_{00} for wine: BC: 4.4 (1 day), 6.9 (7 days), and 10.6 (30 days); CE: 2.6 (1 day), 5.0 (7 days), and 6.5 (30 days); GB: 2.9 (1 day), 5.6 (7 days), and 8.7 (30 days); SB: 3.0 (1 day), 5.3 (7 days), and 6.6 (30 days) - ΔE_{00} for cola: BC: 0.3 (1 day), 0.4 (7 days), and 0.5 (30 days); CE: 0.4 (1 day), 0.4 (7 days), and 0.5 (30 days); GB: 0.5 (1 day), 0.7 (7 days), and 0.8 (30 days); SB: 0.3 (1 day), 0.3 (7 days), and 0.5 (30 days) - ΔE_{ab} for energetic drink: BC: 0.3 (1 day), 0.6 (7 days), and 0.5Δ (30 days); CE: 0.5 (1 day), 0.6 (7 days), and 0.6Δ (30 days); GB: 0.4 (1 day), 0.5 (7 days), and 0.6 (30 days); SB: 0.3 (1 day), 0.4 (7 days), and 0.4 (30 days)	-	-
Kang et al., 2020[47]	- Cerasmart 200 - Cerasmart 300 - KZR-CAD HR - KZR-CAD HR 3 - Estelite Block - Estelite P Block - Katana Avencia Block - Katana Avencia P Block - Mazic Duro - Duro Ace	- n: 15 - 10 x 10 x 2 mm	- ΔE_{ab} for simulated wine: CE2: 0.9 (1 week), 0.9 (2 week), 3.1 (4 weeks), 4.9 (6 weeks), 5.7 (8 weeks), 7.2 (12 weeks); CE3: 1.2 (1 week), 1.2 (2 week), 4.5 (4 weeks), 5.6 (6 weeks), 7.0 (8 weeks), 9.6 (12 weeks); KZR: 1.0 (1 week), 1.2 (2 week), 5.7 (4 weeks), 5.7 (6 weeks), 5.5 (8 weeks), 5.6 (12 weeks); KZR3: 0.8 (1 week), 0.9 (2 week), 3.8 (4 weeks), 5.6 (6 weeks), 7.7 (8 weeks), 9.6 (12 weeks); EB: 0.6 (1 week), 0.7 (2 week), 2.5 (4 weeks), 3.2 (6 weeks), 3.2 (8 weeks), 4.5 (12 weeks); EPB: 0.5 (1 week), 0.6 (2 week), 3.3 (4 weeks), 4.0 (6 weeks), 4.3 (8 weeks), 4.5 (12 weeks); KA: 0.5 (1 week), 0.6 (2 week), 0.7 (4 weeks), 1.2 (6 weeks), 1.4 (8 weeks), 2.1 (12 weeks); KAP: 1.9 (1 week), 2.6 (2 week), 5.6 (4 weeks), 6.7 (6 weeks), 7.6 (8 weeks), 8.5 (12 weeks); MD: 1.0 (1 week), 1.1 (2 week), 2.3 (4 weeks), 2.8 (6 weeks), 3.7 (8 weeks), 4.0 (12 weeks); DA: 1.0 (1 week), 1.3 (2 week), 2.5 (4 weeks), 2.7 (6 weeks), 3.5 (8 weeks), 3.5 (12 weeks)	- ΔTP_{ab} for simulated wine: CE2: 0.02 (1 week), 0.3 (2 week), 2.1 (4 weeks), 3.1 (6 weeks), 4.7 (8 weeks), 5.7 (12 weeks); CE3: -0.4 (1 week), -0.2 (2 week), 2.0 (4 weeks), 2.8 (6 weeks), 3.5 (8 weeks), 4.6 (12 weeks); KZR: -0.1 (1 week), -0.1 (2 week), 4.0 (4 weeks), 4.5 (6 weeks), 3.8 (8 weeks), 3.8 (12 weeks); KZR3: -0.2 (1 week), 0.03 (2 week), 2.9 (4 weeks), 3.7 (6 weeks), 4.6 (8 weeks), 6.0 (12 weeks); EB: -0.1 (1 week), 0.04 (2 week), 1.2 (4 weeks), 1.8 (6 weeks), 2.2 (8 weeks), 2.1 (12 weeks); EPB: 0.2 (1 week), 0.2 (2 week), 2.5 (4 weeks), 3.1 (6 weeks), 3.2 (8 weeks), 3.3 (12 weeks); KA: -0.1 (1 week), -0.01 (2 week), -0.6 (4 weeks), 1.0 (6 weeks), 1.1 (8 weeks), 1.3 (12 weeks); KAP: -0.8 (1 week), -1.1 (2 week), -0.4 (4 weeks), 0.2 (6 weeks), 0.7 (8 weeks), 1.8 (12 weeks); MD: -0.3 (1 week), -0.3 (2 week), 0.8 (4 weeks), 1.8 (6 weeks), 2.2 (8 weeks), 3.3 (12 weeks); DA: -0.3 (1 week), -0.4 (2 week), 0.2 (4 weeks), 0.5 (6 weeks), 0.6 (8 weeks), 1.3 (12 weeks)	-
Sayan et al., 2020[48]	- Lava Ultimate (A2) - Vita Enamic	- n: 40 - 1.2-mm thick	- ΔE_{ab} for coffee: LU: 10.5 (30 days) and 14.2 (120 days); VE: 4.4 (30 days) and 6.5 (120 days) - ΔE_{ab} for wine: LU: 8.7 (30 days) and 16.5 (120 days); VE: 10.3 (30 days) and 20.2 (120 days) - ΔE_{ab} for tea: LU: 11.9 (30 days) and 17.4 (120 days); VE: 4.2 (30 days) and 11.4 (120 days)	-	-
Seyidaliyeva et al., 2020[49]	- Grandio Blocs (A3-HT) - Vita Enamic	- n: 60 each - 9 x 9 x 2 mm	- ΔE_{00} for tea: GB: 4.8; VE: 4.9 - ΔE_{00} for wine: GB: 13.2; VE: 11.6 - ΔE_{00} for cola: GB: 0.7; VE: 0.6 - ΔE_{00} for curry solution: GB: 4.8; VE: 3.8	-	-
Younis et al., 2020[50]	- Vita Enamic	- n: 21 - 12 x 14 x 2 mm	- ΔE_{ab} for coffee: 2.0 - ΔE_{ab} for cola: 1.5	-	-
Adawi et al., 2021[16]	- Vita Enamic	- n: 32 - 2-mm thick	- ΔE_{ab} for coffee 1: 2.9 (2 weeks), 1.4 (4 weeks), and 1.0 (12 weeks) (polished) - ΔE_{ab} for coffee 2: 3.0 (2 weeks), 1.7 (4 weeks), and 1.2 (12 weeks) (glazed)	-	-
Aldosari et al., 2021[51]	- Vita Enamic (1M2-HT)	- n: 32mm - 10 x 10 x 2 mm	- ΔE_{ab} for coffee: 3.4 (polished) and 3.2 (glazed)	-	-
Sağlam et al., 2021[53]	- Cerasmart	- n: 20 - 12 x 14 x 1.5 mm	- ΔE_{ab} for coffee: 2.6	-	-
Sarıkaya & Dilli, 2021[54]	- Lava Ultimate (A2-HT) - Vita Enamic (2M2-HT)	- n: 36 - 1-mm thick	- ΔE_{00} for coffee: LU: 2.3; VE: 1.3 - ΔE_{00} for energetic drink: LU: 1.0; VE: 0.8	-	-
Silva et al., 2021[55]	- Lava Ultimate (A2-HT)	- n: 60 - 1-mm thick	- ΔE_{00} for coffee: LU (composite polishing kit): 4.1; LU (ceramic polishing kit): 2.5	- ΔTP_{ab} for coffee: LU (composite polishing kit): 0.2; LU (ceramic polishing kit): -0.1	- WI_D for coffee: LU (composite polishing kit): -5.2; LU (ceramic polishing kit): -8.1
Stamenkovic et al., 2021[56]	- Cerasmart (A2-LT) - Lava Ultimate (A2-LT) - Shofu Block HC (A2-LT) - Vita Enamic (2M2-T)	- n: 48 - 1-mm thick	- ΔE_{00} for coffee: CE: 1.5 (60 days) and 3.1 (120 days); LU: 4.2 (60 days) and 6.5 (120 days); SB: 2.8 (60 days) and 5.0 (120 days); VE: 2.1 (60 days) and 3.9 (120 days) - ΔE_{00} for wine: CE: 1.1 (60 days) and 1.6 (120 days); LU: 2.0 (60 days) and 2.8 (120 days); SB: 1.8 (60 days) and 2.8 (120 days); VE: 1.6 (60 days) and 2.6 (120 days)	-	-
Tango et al., 2021[58]	- Cerasmart (A2-LT) - Lava Ultimate (A2-LT) - Shofu Block HC (A2-LT) - Vita Enamic (2M2-T)	- n: 48 - 1-mm thick	-	- TP_{00} for coffee: CE: 12 (60 hours), 100.5 (120 hours); LU: 13.2 (60 hours), 93.5 (120 hours); SB: 13.5 (60 hours), 94.2 (hours); VE: 8.7 (60 hours), 93.8 (hours) - TP_{00} for wine: CE: 12.4 (60 hours), 98.9 (120 hours); LU: 13.3 (60 hours), 95.3 (120 hours); SB: 13.6 (60 hours), 95.8 (120 hours); VE: 8.5 (60 hours), 93.6 (120 hours)	-
Yildirim & Recen, 2021[59]	- Cerasmart (A2-HT)	n=13 - 7 x 12 x 0.8 mm	- ΔE_{00} for coffee: 3.9	- ΔTP_{00} for coffee: 14.9	-
Abouraya & Sabry, 2022[60]	- Lava Ultimate (A2-HT) - Vita Enamic (2M2-HT)	- n=15 each - 14 x 12 x 2 mm	- ΔE_{ab} for coffee: LU: 4.1; VE: 5.4 - ΔE_{ab} for cola: LU: 4.1; VE: 1.9	-	-
Al Ahmari et al., 2022[61]	- Vita Enamic	- n: 27 - 1.5-mm thick	- ΔE_{00} for coffee: 1.9 (before regular toothbrush), 1.8 (before electrical toothbrush), and 1.5 (before mouthwash) (15 days) - ΔE_{00} for coffee: 1.7 (after regular toothbrush), 1.6 (after electrical toothbrush), and 1.8 (after mouthwash) (30 days)	-	-
Alsilani et al., 2022[23]	- Vita Enamic (2M2-T)	- n: 10 - 1-mm thick	- ΔE_{ab} for coffee: 8.0 - ΔE_{ab} for cola: 4.3	-	-
Andrade et al., 2022[20]	- Brava Block (A2-LT) - Cerasmart (A2-LT) - Grandio Blocs (A2-LT) - Lava Ultimate (A2-LT)	- n: 20 - 1-mm thick	- ΔE_{00} for staining broth: BB: 2.5; CE: 3.0; GB: 3.4; LU: 5.2ΔE_{00}	- TP_{ab} for staining broth: BB: 11.7; CE: 14.2; GB: 11.9; LU: 15.17	- ΔG for staining broth: BB: -4.9; CE: -13.3; GB: -2.1; LU: -11.2 - ΔF for staining broth: BB: -167.1; CE: -50.5; GB: -33.4; LU: -25.6
Dalforno et al., 2022[62]	- Vita Enamic (1M2-T) - Brava Block (A2-HT)	- n: 12 each - Ø 10 mm; 1.2-mm thick	- ΔE_{00} for wine: VE: 3.7 (15 days) and 4.9 (30 days); BB: 4.2 (15 days) and 5.5 (30 days)	- TP_{00} for wine: VE: 13.5 (15 days) and 12.8 (30 days); BB: 25.3 (15 days) and 23.3 (30 days)	-
Elsaka et al., 2022[29]	- Grandio Blocs (A2-HT) - Lava Ultimate (A2-HT)	- n: 20 - 1.5-mm thick	- ΔE_{00} for coffee: GB: 2.6; LU: 3.1 - ΔE_{00} for tea: GB: 2.4; LU: 2.8 - ΔE_{00} for cola: GB: 2.1; LU: 2.5 - ΔE_{00} for ginger: GB: 2.7; LU: 2.3	- ΔTP_{ab} for coffee: GB: -0.6; LU: -0.6 - ΔTP_{ab} for tea: GB: -0.5; LU: -0.5 - ΔTP_{ab} for cola: GB: -0.4; LU: -0.4 - ΔTP_{ab} for ginger: GB: -0.6; LU: -0.5	- WI_D for coffee: GB: -7.9; LU: -8.8 - WI_D for tea: GB: -3.4; LU: -4.1 - WI_D for cola: GB: -3.1; LU: -3.0 - WI_D for ginger: GB: -2.2; LU: -2.2
Intralawan et al., 2022[63]	- Vita Enamic	- n: 126 - 1.5-mm thick	- ΔE_{00} for coffee: 0.8 (1 week), 0.9 (2 weeks), and 1.4 (1 month) - ΔE_{00} for cola: 0.6 (1 week), 0.7 (2 weeks), and 0.9 (1 month)	- ΔTP_{ab} for coffee: -0.4 (1 week), -0.6 (2 weeks), and –0.9 (1 month) - ΔTP_{ab} for cola: -0.4 (1 week), -0.1 (2 weeks), and –0.1 (1 month)	-
Jalali et al., 2022[64]	- Mazic Duro - Vita Enamic	- n: 60 each - 1-mm thick	- ΔE_{ab} for coffee: MD: 1.0 (polished) to 3.1 (glazed); VE: 0.6 (polished) and 3.3 (glazed) - ΔE_{ab} for carrot juice: MD: 1.6 (polished) to 3.5 (glazed); VE: 0.8 (polished) and 2.1 (glazed)	-	-
Qaraghuli et al., 2022[65]	- Vita Enamic	- n: 15 - 10 x 12 x 2.5 mm	- ΔE_{ab} for coffee: 0.4 - ΔE_{ab} for wine: 2.2 - ΔE_{ab} for tea: 0.7	-	-
Ugurlu, 2022[66]	- Cerasmart	- n: 20 - 2-mm thick	- ΔE_{ab} for wine: 4.8	-	-
Yerliyurt & Sarıkaya, 2022[17]	- Lava Ultimate (A2-HT) - Vita Enamic (2M2-HT)	- n=6 each - 1-mm thick	- ΔE_{00} for coffee: LU: 3.5 (1 day), 5.8 (7 days), 6.6 (14 days), and 7.7 (28 days); VE: 1.5 (1 day), 2.6 (7 days), 2.0 (14 days), and 3.5 (28 days) - ΔE_{00} for coffee-tea: LU: 2.8 (1 day), 7.1 (7 days), 9.2 (14 days), and 12.7 (28 days); VE: 2.1 (1 day), 5.9 (7 days), 7.6 (14 days), and 11.9 (28 days) - ΔE_{00} for coffee-cola: LU: 2.0 (1 day), 3.8 (7 days), 4.0 (14 days), and 5.1 (28 days); VE: 1.3 (1 day), 2.1 (7 days), 1.8 (14 days), and 3.1 (28 days) - ΔE_{00} for coffee-wine: LU: 3.8 (1 day), 8.9 (7 days), 10.9 (14 days), and 11.2 (28 days); VE: 2.3 (1 day), 7.7 (7 days), 9.7 (14 days), and 12.8 (28 days) - ΔE_{00} for coffee-pomegranate juice: LU: 4.0 (1 day), 7.5 (7 days), 6.4 (14 days), and 7.7 (28 days); VE: 1.9 (1 day), 5.4 (7 days), 4.1 (14 days), and 5.6 (28 days) - ΔE_{00} for coffee-turnip juice: LU: 3.4 (1 day), 5.2 (7 days), 5.2 (14 days), and 6.6 (28 days); VE: 1.1 (1 day), 2.4 (7 days), 1.6 (14 days), and 2.5 (28 days)	-	-
Ashtiani et al., 2023[67]	- Lava Ultimate (A3) - Crystal Ultra (A3) - Vita Enamic	- n: 10 - 12 x 14 x 1.5 mm	- ΔE_{00} for tea: LU: 6.4; CU: 2.5; VE: 4.4 - ΔE_{00} for grape juice: LU: 10.6; CU: 1.3; VE: 1.4	-	-
Bozogullari & Temizci, 2023[68]	- Cerasmart (A2) - Vita Enamic	- n: 20 - 14 x 12 x 2 mm	- ΔE_{00} for coffee: CE: 1.4; VE: 2.4	-	-
Bayraktar et al., 2024[31]	- Lava Ultimate - Cerasmart - Shofu Block HC - Brilliant Crios - Vita Enamic	- n: 20 - 3-mm thick	- ΔE_{00} for coffee: LU: 2.7; CE: 3.9; SB: 2.6; BC: 4.6; VE: 4.3	-	-
Çakmak et al., 2024[69]	- Cerasmart	- n: 30 - 1-mm thick	- ΔE_{00} for coffee: 0.5 (polished) and 1.0 (glazed)	-	-
Bek Kurklu & Sonkaya, 2024[70]	- Lava Ultimate - Cerasmart - Vita Enamic	- n: 12 - 2-mm thick	- ΔE_{00} for coffee: LU: 1.8 (24h), 2.4 (1 week), and 2.7 (1 month); CE: 1.0 (24h), 1.3 (1 week), and 1.9; VE:1.4 (24h), 1.8 (1 week), and 2.0 - ΔE_{00} for wine: LU: 2.1 (24h), 3.1 (1 week), and 4.0 (1 month); CE: 2.4 (24h), 3.3 (1 week); and 4.3, VE:2.9 (24h), 3.6 (1 week); and 4.6	- ΔTP_{00} for coffee: LU: 0.6 (24h), 0.3 (1 week), and 0.1 (1 month); CE: -0.3 (24h), -0.2 (1 week), and -0.1; VE: 0.0 (24h), 0.7 (1 week), and -0.3 - ΔTP_{00} for wine: LU: -0.1 (24h), -0.5 (1 week), and -0.5 (1 month); CE: -0.1 (24h), -0.3 (1 week), and -0.4; VE:0.6 (24h), 0.3 (1 week), and -0.3	-
Schneider et al., 2024[72]	- Brava Block (A1 HT and LT)	- n: 10 each - 0.5-mm thick	- ΔE_{00} for coffee: BB HT: 2.8 (15 min), 4.4 (48 min), 5.9 (336 min), 7.9 (1440 min), 10.3 (8460 min), 11.3 (35,040 min) - ΔE_{00} for coffee: BB LT: 2.9 (15 min), 4.1 (48 min), 5.9 (336 min), 7.3 (1440 min), 10.0 (8460 min), 11.2 (35,040 min)	- TP_{00} for coffee: BB HT: 17.1 (15 min), 16.8 (48 min), 16.3 (336 min), 15.3 (1440 min), 15.2 (8460 min), 15.0 (35,040 min) - TP_{00} for coffee: BB LT: 16.4 (15 min), 16.4 (48 min), 15.8 (336 min), 15.8 (1440 min), 15.5 (8460 min), 15.3 (35,040 min) - ΔTP_{00} for coffee: BB HT: 0.5 (15 min), 0.7 (48 min), 1.3 (336 min), 2.3 (1440 min), 2.4 (8460 min), 2.5 (35,040 min) - ΔTP_{00} for coffee: BB LT: 0.8 (15 min), 0.8 (48 min), 1.3 (336 min), 1.4 (1440 min), 1.7 (8460 min), 1.9 (35,040 min)	- ΔL′ for coffee: BB HT: -3.0 (15 min), -4.3 (48 min), -6.4 (336 min), -7.4 (1440 min), -10.0 (8460 min), -11.4 (35,040 min) - ΔL′ for coffee: BB LT: -3.2 (15 min), -4.0 (48 min), -6.4 (336 min), -8.2 (1440 min), -11.0 (8460 min), -12.4 (35,040 min) - ΔC′ for coffee: BB HT: 2.6 (15 min), 4.3 (48 min), 5.0 (336 min), 7.8 (1440 min), 9.7 (8460 min), 10.2 (35,040 min) - ΔC′ for coffee: BB LT: 2.6 (15 min), 4.3 (48 min), 5.1 (336 min), 6.0 (1440 min), 8.5 (8460 min), 9.1 (35,040 min) - ΔH′ for coffee: BB HT: -1.3 (15 min), -2.2 (48 min), -3.2 (336 min), -4.7 (1440 min), -6.1 (8460 min), - 6.6 (35,040 min) - ΔH′ for coffee: BB LT: -1.4 (15 min), -2.1 (48 min), -3.2 (336 min), -3.5 (1440 min), -5.2 (8460 min), -5.8 (35,040 min)
Krajangta et al., 2024[73]	- Cerasmart (LT)	- n: 20 - 1.5-mm thick	- ΔE_{00} for coffee: 2.6	- ΔTP_{ab} for coffee: -0.39	-
Zhang et al., 2024[74]	- Brilliant Crios - Lava Ultimate - Hyramic - Shofu HC - Vita Enamic	- n: 50 each - 1.0-mm thick	- ΔE_{00} for coffee: BC: 0.6 (3 days), 0.8 (7 days), 1.1 (14 days); LU: 0.4 (3 days), 0.7 (7 days), 1.6 (14 days); HY: 0.6 (3 days), 0.9 (7 days), 1.0 (14 days); SB: 0.5 (3 days), 0.6 (7 days), 1.0 (14 days); VE: 0.6 (3 days), 0.7 (7 days), 0.9 (14 days). - ΔE_{00} for wine: BC: 0.7 (3 days), 1.1 (7 days), 1.3 (14 days); LU: 0.5 (3 days), 1.1 (7 days), 2.1 (14 days); HY: 0.7 (3 days), 1.2 (7 days), 1.8 (14 days); SB: 0.6 (3 days), 1.1 (7 days), 1.3 (14 days); VE: 0.7 (3 days), 0.8 (7 days), 1.3 (14 days). - ΔE_{00} for tea: BC: 0.6 (3 days), 0.8 (7 days), 0.9 (14 days); LU: 0.4 (3 days), 0.8 (7 days), 1.4 (14 days); HY: 0.6 (3 days), 0.8 (7 days), 1.5 (14 days); SB: 0.5 (3 days), 1.0 (7 days), 1.0 (14 days); VE: 0.4 (3 days), 0.6 (7 days), 0.9 (14 days). - ΔE_{00} for cola: BC: 0.6 (3 days), 0.6 (7 days), 0.8 (14 days); LU: 0.3 (3 days), 0.4 (7 days), 0.9 (14 days); HY: 0.5 (3 days), 0.6 (7 days), 0.9 (14 days); SB: 0.4 (3 days), 0.6 (7 days), 0.7 (14 days); VE: 0.4 (3 days), 0.7 (7 days), 0.9 (14 days).	- ΔTP_{00} for coffee: BC: -0.3 (3 days), -0.3 (7 days), -0.8 (14 days); LU: -0.2 (3 days), -0.5 (7 days), -0.8 (14 days); HY: -0.04 (3 days), 0.7 (7 days), -1.0 (14 days); SB: 0.02 (3 days), -0.4 (7 days), -0.6 (14 days); VE: -0.3 (3 days), -0.6 (7 days), -0.7 (14 days). - ΔTP_{00} for wine: BC: -0.3 (3 days), -0.5 (7 days), -1.1 (14 days); LU: -0.3 (3 days), -0.6 (7 days), -1.3 (14 days); HY: -0.3 (3 days), -0.7 (7 days), -1.1 (14 days); SB: -0.01 (3 days), -0.4 (7 days), -0.7 (14 days); VE: -0.4 (3 days), -0.8 (7 days), -0.9 (14 days). - ΔTP_{00} for tea: BC: -0.4 (3 days), -0.4 (7 days), -0.9 (14 days); LU: -0.1 (3 days), -0.2 (7 days), -0.8 (14 days); HY: -0.4 (3 days), -0.6 (7 days), 1.1 (14 days); SB: -0.1 (3 days), -0.3 (7 days), -0.6 (14 days); VE: -0.4 (3 days), -0.4 (7 days), -0.4 (14 days). - ΔTP_{00} for cola: BC: -0.3 (3 days), -0.4 (7 days), -0.5 (14 days); LU: -0.02 (3 days), -0.12 (7 days), -0.4 (14 days); HY: -0.1 (3 days), -0.4 (7 days), -0.7 (14 days); SB: 0.4 (3 days), 0.06 (7 days), -0.5 (14 days); VE: -0.3 (3 days), -0.5 (7 days), -0.7 (14 days).	-
Çakmak et al., 2025[75]	- Brilliant Crios - Vita Enamic	- n: 10 each - 1.0-mm thick	- ΔE_{00} for coffee: BC:1.1; VE:0.9	-	-

* HT (High Translucency), LT (Low Translucency), T (Translucency).
* BB (Brava Block), BC (Brilliant Crios), CE (Cerasmat), DA (Duro Ace), EB (Estelite Block), EPB (Estelite P Block), GB (Grandio Blocs), HY (Hyramic), KA (Katana Avencia Block), KAP (Katana Avencia P Block), KZR (KZR-CAD HR), KZR3 (KZR-CAD HR 3), LU (Lava Ultimate), MD (Mazic Duro), MD (Mazic Duro), SB (Shofu Block HC), VE (Vita Enamic).
* CR (Contrast Ratio), GU (Gloss Unit), WI_D (Whiteness Index), ΔC′ (Chroma differences), ΔG (Gloss differences), ΔF (Fluorescence differences), ΔH′ (Hue differences), ΔL′ (Lightness differences), ΔWI_D (Whiteness Index differences).



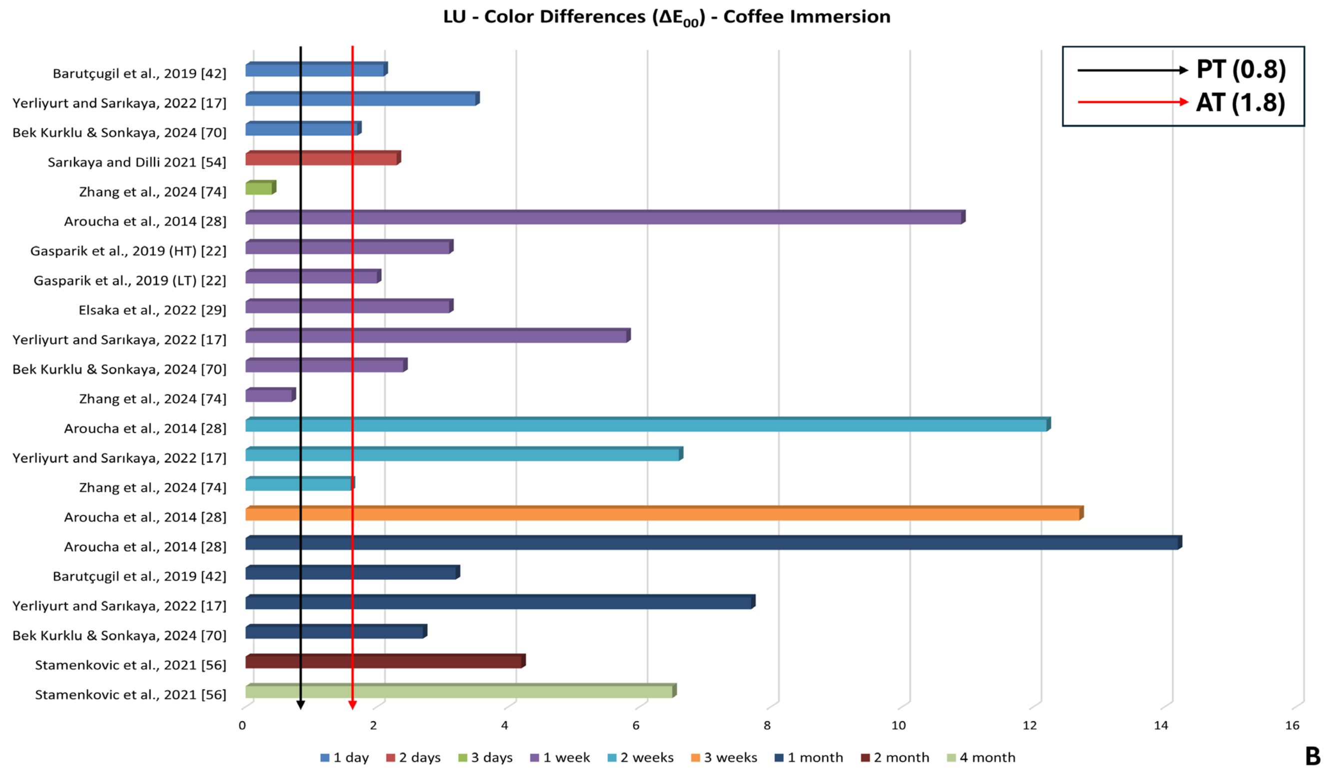


Figure 2A and B: Color differences (ΔEab and ΔE00) for Lava Ultimate after immersion in coffee over time.
*LU (Lava Ultimate), LT (low translucency), HT (high translucency), PT (50:50% perceptibility threshold), AT (50:50% acceptability threshold).

coordinates (CIELab or CIEDE2000).[32,33] PT corresponds to the smallest color difference detected by an observer, while a color difference acceptable to 50% of the observers corresponds to a 50:50% acceptability threshold.[32]

Translucency after immersion in coffee was evaluated in 15 studies.[14,15,22,29,39,42,43,55,58,59,63,70,72-74] TP_{ab} values varied from 14.1 (Vita Enamic for 48 hours)[39] to 23 (Shofu Block HC for 1 week)[22] and TP_{00} from 8.7 (Vita Enamic for 60 hours)[58] to 17.1 (Brava Block for 15 minutes).[72] These differences are probably related to the different immersion times and the variations in thickness between studies (from 0.5 to 2.0 mm – Table 2). One study evaluated the contrast ratio with increased opacity of materials after 1-month immersion.[42] Differences between translucency parameters indicated a reduction in translucency after immersion in coffee.[14,15,22,29,42,43,55,59,63,70,72-75] Three studies that employed bleaching agents after coffee staining of CAD/CAM composite materials studied the whiteness index (WID) and noted a reduction in this parameter.[22,29,55]

STAINING AFTER IMMERSION IN RED WINE

Generally, wine is composed of water (86%), ethanol (12%), glycerol and polysaccharides (1%), organic acids (0.4%), polyphenols such as tannins and anthocyanin (0.1% - responsible for the color), and aromatic volatile compounds (0.5% - responsible for the smell and flavor). Water establishes the physical, chemical, and sensory characteristics of wine, while ethanol can inhibit the action of undesirable microorganisms during fermentation, in addition to acting as a solvent for the extraction of pigments.[85]

Phenolic compounds determine wine's sensory and chromatic characteristics and are more concentrated in red wine.[86] Among these compounds, tannins influence the color and astringency of wines, while anthocyanins (mostly present in red wine) are mainly responsible for their color.[87] Anthocyanins can absorb light in the visible spectrum, conferring various colors depending on the pH of the medium: reddish in acidic media, from lilac to purple in neutral media, bluish/greenish in basic media, and yellowish in extremely basic media.

These pigments seem related to staining in resin-based materials after wine immersion.[45,85] However, studies are inconclusive about the staining mechanism involved after immersion in wine, suggesting that a combination of factors occurs.[28,86] The alcohol in wine acts by softening the resin matrix of the material, which may facilitate the penetration of pigments into the matrix.[38] Red wine's low pH (approximately 3.8) can also promote discoloration when in contact with the surface of these materials.[56] In addition, the acidic and alcoholic characteristics of red wine lead to increased surface roughness, contributing to staining.[70,87] Thus, the color change promoted by wine is a complex process resulting from increased surface roughness and resin matrix degradation, which enhances material staining by facilitating pigment adsorption and penetration.[15,31]

Among the 24 studies that immersed samples in red wine, immersion times ranged from 24 hours to 120 days, and the solution was changed from daily to up to every 12 days *(Table 2)*. Two studies combined thermocycling with wine immersion,[17,49] while one study employed a simulated red wine solution (25 mg of Kuromanin chloride used as an edible red pigment and poured into 500 mL of a 10% ethanol solution).[47] Although the pigment anthocyanin affects discoloration directly, it is difficult to quantitatively compare its effects because commercially available red wines contain other components such as alcohol, acids, chromogens, and tannins. Temperature variations (from 37 °C to 55 °C) were also evaluated after immersing CAD/CAM composite materials in red wine for 1 and 7 days, and the authors observed that specimens stored at 37 °C showed significantly less discoloration than those stored at 55 °C.[44]

Regarding ΔE, ΔE_{ab} values varied from 0.6 to 31.9 and ΔE_{00} from 0.5 to 10.6 after red wine immersion of Lava Ultimate,[44,28,74] Vita Enamic,[19,74] and Brilliant Crios[45,74] *(Table 3)*. The higher color difference values obtained with red wine immersion indicate that it may have greater staining potential than coffee and tea.[17,38,49] One study evaluated the translucency parameter TP_{00} at 60 and 120 hours.[58] Like coffee immersion, the translucency of CAD/CAM composite materials decreased after red wine immersion.[58] Figure 4 (A and B) shows the ΔE_{ab} and ΔE_{00} values for the CAD/CAM composite materials after wine immersion.

STAINING AFTER IMMERSION IN TEA

Tea contains oxalic, malic, and citric acids,[88] and its staining capacity may originate from tannic acid and pigments in its composition.[28] The adsorption of tannins on the surface of materials causes discoloration by exposure to tea.[52] Moreover, tea immersion can increase surface roughness due to tea's chemical erosion action as an acidic substance (like coffee), contributing to staining.[15] Tea's low polarity may also contribute to staining, allowing pigments to penetrate deeper into the resin matrix.[28,29]

In the 15 studies that used tea, immersion times ranged from 24 hours to 120 days *(Table 2)*. Two studies combined thermocycling with tea immersion,[17,49] and one study immersed samples in a coffee-tea combined solution.[17] After immersion, ΔE_{ab} values ranged from 0.7 to 17.4 (for Vita Enamic)[65,48] and ΔE_{00} from 0.4 to 11.0 (for Lava Ultimate).[28,74] The variations in color differences found after steeping in tea are probably related to the wide variety of teas available and the different immersion times used. Coffee can promote greater color changes than tea, especially in Bis-GMA-based materials.[23] One study evaluated the translucency parameter TP00 and found values of 16 to 20 for the tested materials after 48 hours of immersion.[39] Three studies assessed differences in translucency (ΔTP_{ab}) and observed reduced translucency after immersion.[25,29,74] *(Table 3)*.

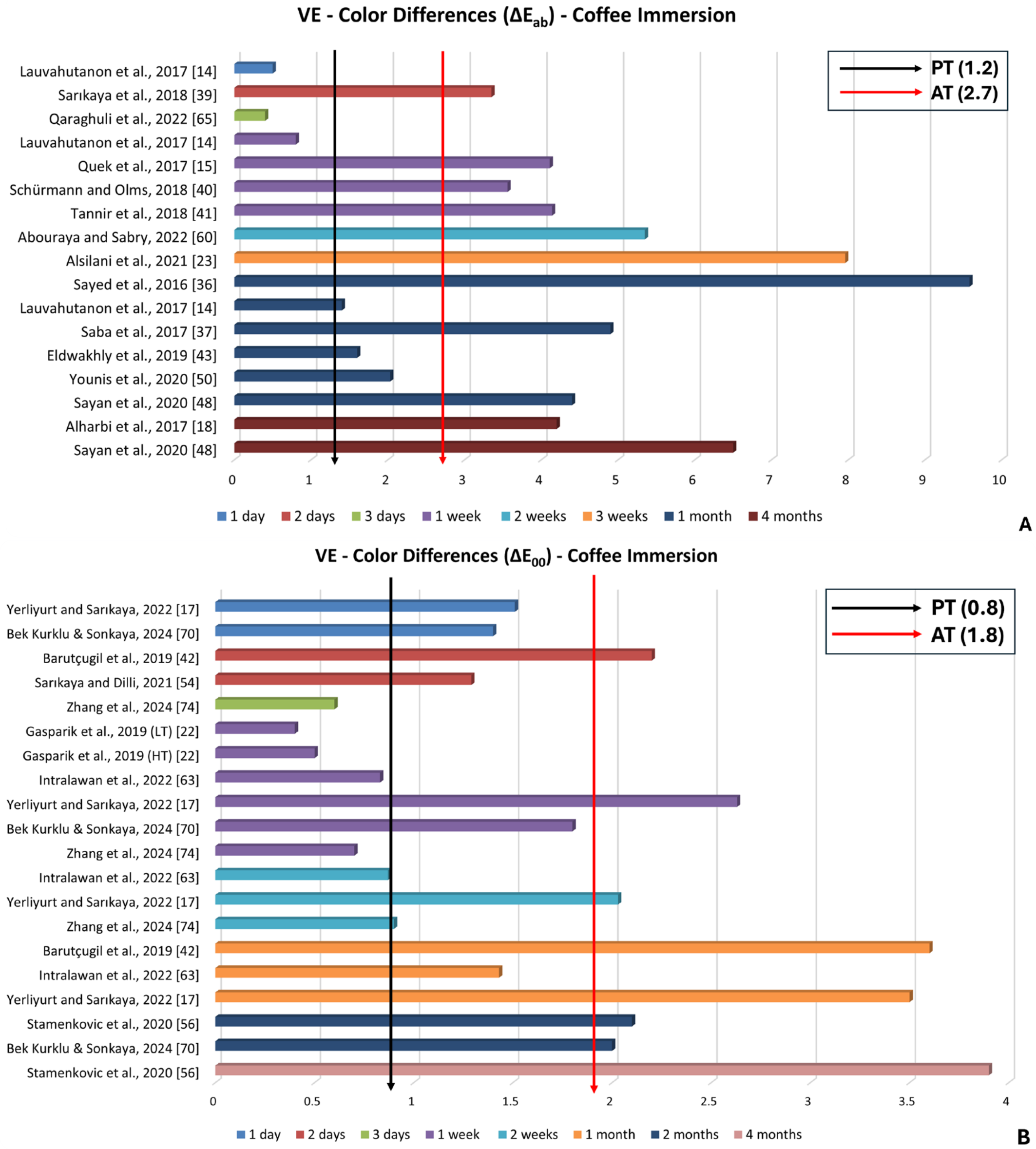
STAINING AFTER IMMERSION IN COLA-BASED BEVERAGES

The low pH (around 2.6) of cola-based beverages appears to be directly related to the higher roughness observed on the surface of CAD/CAM composite materials after immersion, facilitating pigment adsorption.[89] Although these beverages have a lower staining capacity, they have higher acidity than coffee and tea.[29,43]

Thirteen studies immersed samples in a cola-based beverage,[15,23,36,29,39,40,43,45,49,50,60,63,74] and one used a coffee-cola combination.[17] Most studies immersed samples at 37 °C, while one used the beverage at 4 °C.36 Color difference ΔE_{ab} values ranged from 0.6 (for Lava Ultimate)[15] to 4.3 (for Vita Enamic)[23] and ΔE_{00} from 0.3 (for Shofu Block HC and Lava Ultimate)[45,74] to 2.5 (for Lava Ultimate)[29] after immersion in cola-based beverages. Only one study evaluated the translucency parameter TP_{ab}, which ranged from 18.0 to 19.8 for Vita Enamic and Lava Ultimate, respectively.[39] One study evaluated the whiteness index (WID) and found it reduced after immersion.[29]

STAINING AFTER IMMERSION IN OTHER BEVERAGES

Twelve studies evaluated the optical properties of CAD/CAM composite materials after immersion in curry solution,[26,44,49] cress solution,[26,44] ginger,[29,4]3 energy drink,[45,54] carrot juice,[35,64] grape juice,[57,67] pomegranate juice,[17] and turnip juice,[17] with immersions of 1 to 30 days *(Table 2)*. The study that employed pomegranate and turnip juices combined them with coffee.[17]



Figures 3A and B: Color differences (ΔE_{ab} and ΔE_{00}) for Vita Enamic after immersion in coffee over time.

An immersion solution combining cranberry juice, black tea, and coffee[34] and a staining solution recommended by ADA (with coffee, black tee, gastric mucin, FD & C red, FD & C yellow 5, red wine, and distilled water)[20] were used to simulate an *in vitro* condition closer to reality.

Curry is composed of different spices, including coriander, ginger, peppers, cardamom, turmeric, nutmeg, cloves, and cinnamon. The main yellowish components of turmeric are curcumin, demethoxycurcumin, and bis-demethoxycurcumin.[90] Curcumin can change its color according to the pH of the medium: it is often reddish in a basic solution and yellowish in neutral and acidic media.[90] The curry solution comprises almost 100% dissolved curcumin powder, with a pH of about 5.9.[26] In turn, cress contains a large amount of lutein, a yellowish-pigmented macular carotenoid found in yellow and dark green vegetables.[91] The cress solution has a neutral pH of about 6.0.[26] The color of the ginger rhizome also results from yellow pigment compounds (curcumin, demethoxycurcumin, and 6-dehydrogingerdione), although their color intensity is lower than that of turmeric.[92] The ginger drink used in the included studies has an alkaline pH of approximately 8.0.[29,43]

Caffeine, taurine, inositol, colorants (such as anthocyanins), acidulants (such as citric acid), and preservatives (such as sorbic and benzoic acids) are present in the composition of energy drinks.[93] These beverages present acidity and abrasive potential,[94] which may contribute to color changes observed.[54]

Natural pigments in the composition of fruits and vegetables are responsible for their color and often play an antioxidant potential.[84] Carrots contain α and β-carotene, which give them a yellowish/reddish color.[95] Grapes have flavonoids that are mainly responsible for their color, which becomes even more intense in juices.[96] Pomegranate juice's color results from anthocyanins and flavonoids, which have antioxidant activity, and color intensity increases with the fruit's ripeness.[97] The color of turnips ranges from white to purple and may be associated with bioactive components such as glucosinolates, isothiocyanate, phenolic compounds, flavonoids, and organic acids.[98]

The solutions used as immersion media showed staining potential with ΔE_{ab} values ranging from 1.3 (Lava Ultimate, Ginger)[43] to 12.5 (Lava Ultimate, Curry solution)[44] and ΔE_{00} from 0.3 (Brilliant Crios and Shofu Block HC, Energetic drink)[45] to 10.6 (Lava Ultimate, grape juice).[67] Two studies evaluated translucency parameter differences ΔTP_{ab} and demonstrated reductions after immersion in ginger drink.[29,43] The gloss and fluorescence were also evaluated after immersion in combined staining solutions, with higher gloss values for polished samples[34] and reduced fluorescence after immersion in this combined solution.[20]

STAINING POTENTIAL OF RESIN-BASED MATERIALS

Staining observed in resin-based materials can be classified as follows: i) extrinsic staining due to the accumulation of bacterial plaque and surface stains; ii) staining related to surface degradation, penetration, and coloring agents' reaction with the material; and iii) intrinsic staining resulting from the oxidation of double bonds that did not react with residual monomers or with the polymer matrix oxidation, and the subsequent diffusion of water with the formation of degradation byproducts.[99]

Composite materials' susceptibility to staining after exposure to coloring agents is associated with the resin matrix's hydrophilicity and the amount of water it absorbs.[100] Materials containing a hydrophilic resin matrix show higher water absorption[99] and may absorb fluids with coloring pigments, resulting in discoloration.[66] On the other hand, the presence of fewer hydrophilic monomers contributes to a greater resistance to color and translucency changes.[63] Studies report that Bis-GMA is the most hydrophilic monomer, followed by TEGDMA, Bis-EMA, and UDMA.[101]

The resin matrix's degree of conversion is directly related to the number of unreacted monomers within the material.[100] A high number of unreacted monomers leads to greater water absorption, with consequent discoloration.[66] Bis-GMA has a lower degree of conversion than UDMA and TEGMA, leading to greater water absorption.[101] Other intrinsic factors related to color changes include the diameter, load, and distribution of inorganic filler particles of the material.[18,87,99] Smaller particle sizes, namely, nanoparticles, result in a large surface area, which may elevate the risk of adverse effects by increasing the polymer matrix's susceptibility to degradation.[66,99]

The studies evaluated high- and low-translucency CAD/CAM composite materials *(Table 3*), but only three evaluated their optical behavior at the different translucency levels provided by the manufacturers.[19,22,72] The results are inconclusive since some studies observed more pronounced color variations in higher-translucency materials, especially over time,[19,22] while others found similar behaviors between high- and low-translucency materials.[72] Figure 5 shows a correlation between the main materials included in this review.

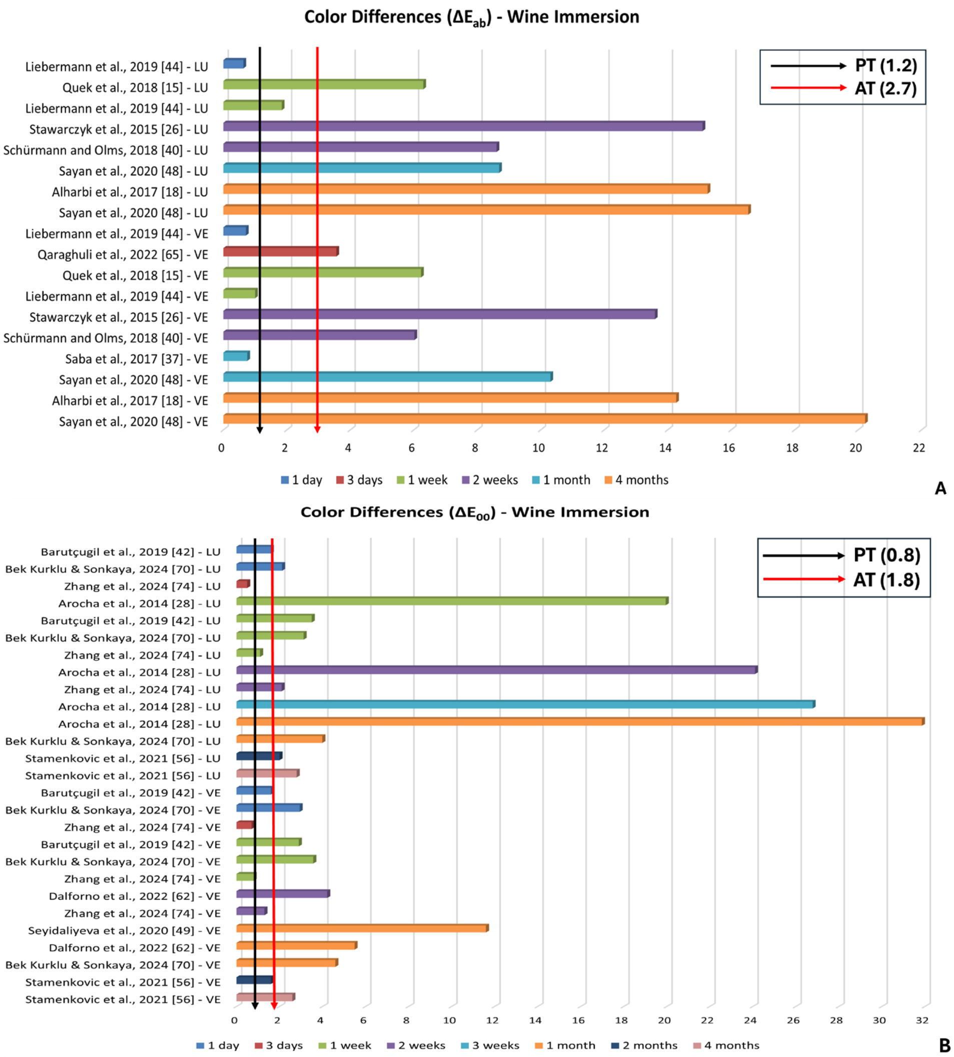
STRATEGIES TO MINIMIZE STAINING IN CAD/CAM COMPOSITE MATERIALS

The included articles reported some strategies to minimize the staining of CAD-CAM composite materials. Among them, the following stand out: i) surface finishing and polishing;[14,16,19,34,35,39,49,51,56,64,66,69] ii) application of a glazing agent;[16,19,51,64,69] iii) whitening,[22,29,38,53] and iv) control with brushing.[55,61,72]

A rougher surface favors bacterial plaque retention by making it more difficult to clean, while smoother surfaces show reduced deposition of pigments and bacteria.[56] Finishing and polishing procedures are techniques known for making the restoration surface smoother and brighter.[14,35,69] These techniques are performed with rubbers and disks, with sequential variations in grain size,[59] associated or not with polishing pastes with diamond particles.[35] Studies reported no significant differences after using different polishing techniques, suggesting that surface smoothness increases the material's resistance to staining, regardless of the technique used.[39] The degree of shine obtained after polishing is closely related to the material's refractive index and topography.[34] Finishing and polishing procedures can be performed in the clinic or the laboratory, and no differences were found in color stability after polishing performed in both contexts.[56] In addition to increasing staining resistance, polishing may increase translucency.[59] Most studies in this review polished the samples' surface before immersion in coloring solutions to standardize the method. Figure 6 compares the staining results obtained by the studies before and after polishing.

Glazing is a surface finish used for ceramic surfaces to reduce their roughness.[51,69] Because glazing is performed under heat treatment, it cannot be done on materials with a resin matrix.[35] Studies that recommended glazing for CAD/CAM composite materials' surfaces performed this procedure in Vita Enamic.[16,19,51,64] The manufacturer of this ceramic claims that the fine-structured feldspar ceramic network is reinforced by a completely homogeneous polymer network capable of withstanding temperature changes.

Bleaching has been suggested as an option for removing stains from restorative materials due to its ability to change tooth color without affecting the morphology of dental restorations.[22,38,53] The effects of the bleaching agent on the stains of restorative materials depend on the nature of the material and the coloring solution.[102] Significant changes in the whiteness index[22,29] and a reduction in translucency[29] were observed after the bleaching of CAD/CAM composite materials. Surfaces stained by coffee, tea, and red wine subjected to the bleaching protocol showed color improvement, although the initial color of the material was not completely restored.[38] However, polishing and bleaching methods are inefficient when the staining reaches deeper layers of the restoration. In such cases, replacement should be considered for more severely affected restorations.[22]



Figures 4A and B: Color differences (ΔE_{ab} and ΔE_{00}) for Lava Ultimate and Vita Enamic after immersion in red wine over time. *LU (Lava Ultimate), VE (Vita Enamic), PT (50:50% perceptibility threshold), AT (50:50% acceptability threshold).

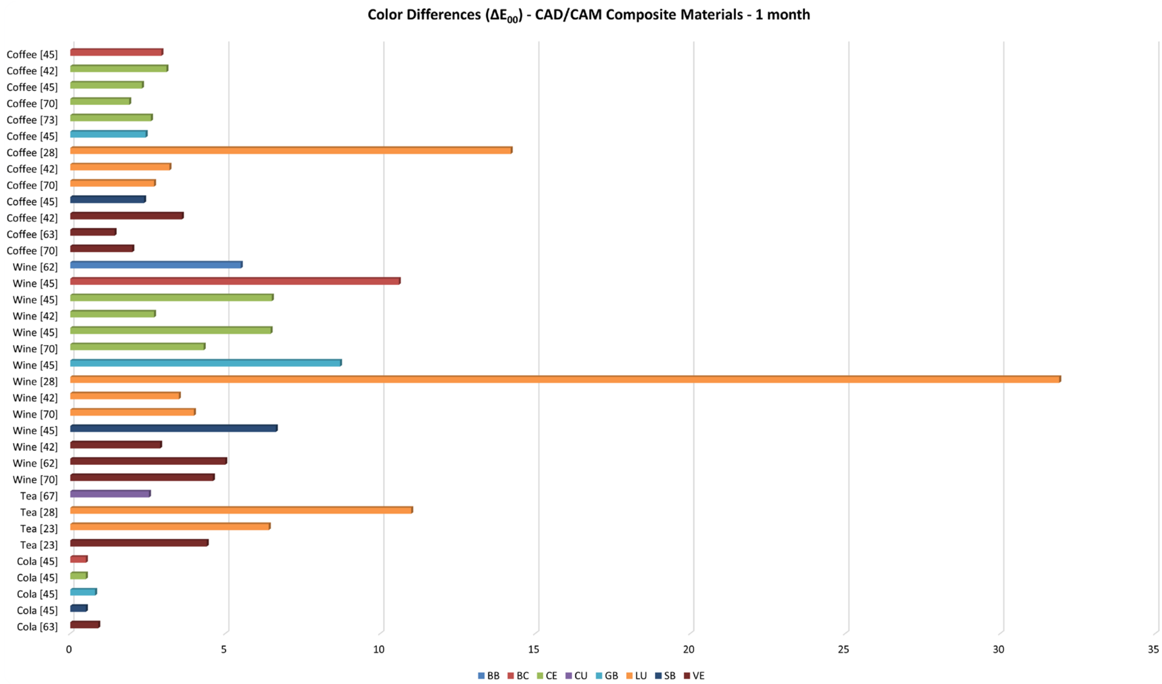


Figure 5: Color differences (ΔE_{00}) for CAD/CAM composite materials in coloring solutions after 1 month. *BB (Brava Block), BC (Brilliant Crios), CE (Cerasmart), CU (Crystal Ultra), GB (Grandio Blocs), LU (Lava Ultimate), SB (Shofu Block HC), VE (Vita Enamic).

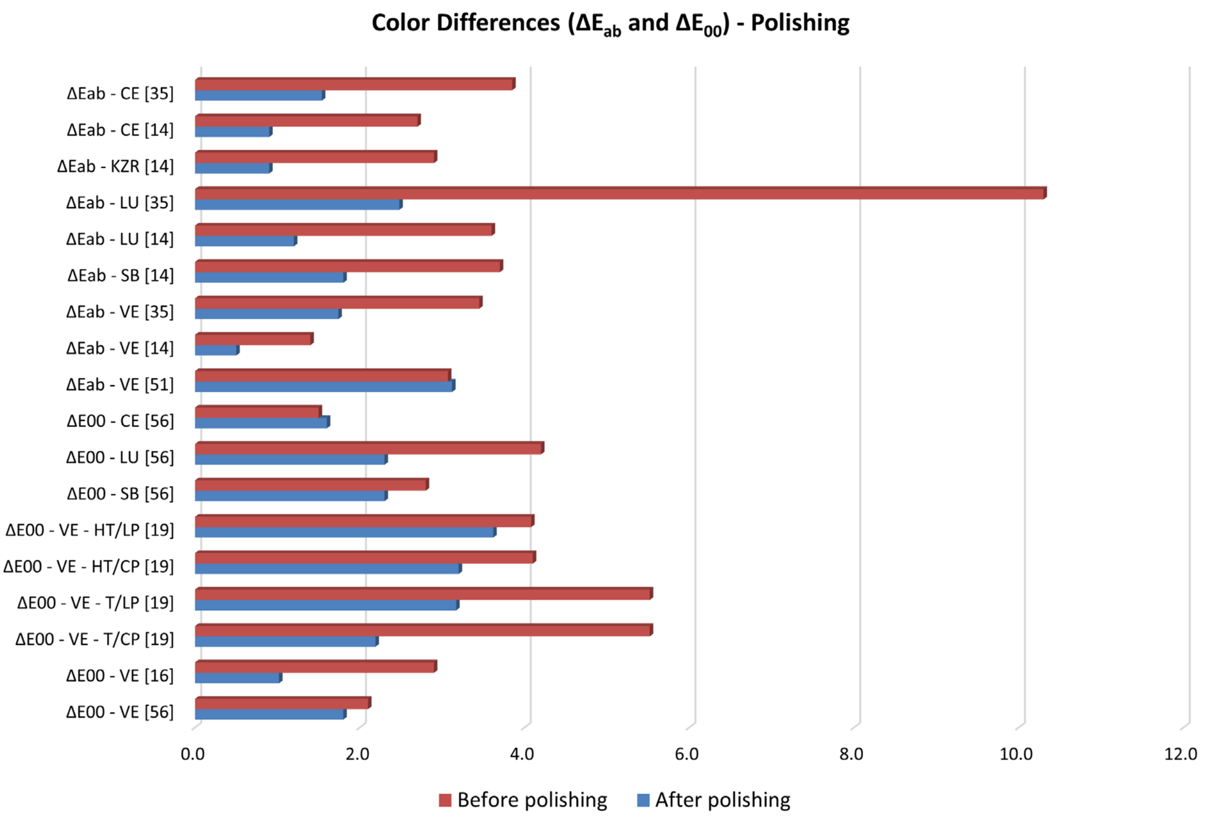


Figure 6: Color differences (ΔE_{ab} and ΔE_{00}) before and after polishing after immersion in coffee.
* CE (Cerasmat), KZR (KZR-CAD HR), LU (Lava Ultimate), SB (Shofu Block HC), VE (Vita Enamic), HT (high translucency), T (translucency), LP (laboratory polishing), CP (clinical polishing).

Periodic polishing can help maintain restorations over time by reducing the discolorations and increasing their longevity.[14,66] However, this procedure is a conservative approach whose success depends on the material and the staining severity.[66] Oral hygiene practices, such as brushing with soft bristles or mechanical brushes, can reduce or even prevent staining of restorations caused by extrinsic pigments.[61,72] The association with toothpaste helps increase the restoration's aesthetic longevity since the toothpaste's abrasive components can eliminate microorganisms and reduce stains on the tooth surface.[103]

RECOMMENDATIONS REGARDING CAD/CAM COMPOSITE MATERIAL SELECTION BASED ON STAINING BEHAVIOR

Below are some recommendations for clinicians when selecting aesthetic material and during the control and monitoring of restorations:

- The materials most susceptible to staining are those that contain a hydrophilic resin matrix (e.g., Bis-GMA)[66,99] (see the composition of the composite materials in Table 1 and their staining potential in Figure 5).
- Among beverages, red wine and coffee have the greatest potential to stain composite materials.[13,22,26,50,70,74,75] Therefore, it is important to inform patients and provide guidance on the excessive use of these beverages.
- Although bleaching could reduce surface staining,[22,29] periodic polishing of the restoration surfaces helps to obtain a smooth surface, which reduces the action of the staining agents, and maintain the restoration over time.[14,66]
- Brushing with soft-bristled brushes or mechanical brushes, combined with toothpaste, helps to reduce and prevent future stains caused by extrinsic pigments.[61,72]

CONCLUSIONS

CAD/CAM composite materials are prone to staining. Although immersion methodologies vary between studies, coffee is the most commonly used staining solution. However, the greatest staining is observed after immersion in red wine and in materials composed of a hydrophilic matrix. Cola-based beverages produced the least staining after immersion. Studies recommend techniques such as polishing, bleaching, and brushing to minimize staining in these materials.

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