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Fortification of Greek Yogurt with Honey, Ginger Extract, and Rice Bran: Effects on Colorimetric and Sensory Attributes during Storage

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ABSTRACT

This study aimed to evaluate the impact of fortified Greek yogurt with honey (3% and 6% by weight/weight), ginger extract (1% and 2% by volume/weight), and rice bran (3% and 6% by weight/weight) on its colorimetric properties and sensory attributes over a storage period of seven days. A comprehensive colorimetric analysis (L*, a*, b*, chroma, hue angle, whiteness index) and sensory evaluation (color, odor, taste, texture, consistency, overall acceptability) were performed. Colorimetric analysis revealed a significant increase in redness and yellowness in fortified formulations compared to the control. The highest redness intensity was observed in yogurt containing 6% honey, 1% ginger extract, and 6% rice bran, while an inverse relationship was identified between rice bran content and brightness. Sensory evaluation demonstrated that the control sample had the highest overall acceptability, followed by yogurt formulation containing 6% honey, 2% ginger extract, and 3% rice bran. Increased honey concentrations improved acceptability, whereas higher rice bran content negatively influenced color perception. These findings provide valuable insights into the formulation of fortified Greek yogurt, emphasizing the importance of balancing colorimetric properties and sensory attributes to optimize consumer acceptance. Future research should focus on refining ingredient ratios, evaluating long-term storage stability and employing more complex experimental designs with additional factor levels to enhance the functionality and appeal of fortified yogurt products.

1-Introduction

Yogurt, a fermented dairy matrix derived primarily from bovine milk [1], is widely recognized as a nutrient-rich food containing peptides, bioactive lipids, and antioxidants that collectively contribute to its antimicrobial, anti-inflammatory, and antioxidative properties [2]. Regular consumption of yogurt has been associated with numerous health benefits, including increased longevity [3], alleviation of symptoms related to anxiety, depression, and stress [4], and reduced risk factors of non-communicable diseases, including colorectal carcinoma, type 2 diabetes, and heart disease [3]. Yogurt can be classified based on multiple parameters, including fat content, fermentation and processing methodologies, and rheological characteristics [5]. Among these, Greek yogurt has garnered considerable interest due to its elevated protein and micronutrient content, positioning it as a functionally enhanced dairy product [6]. Furthermore, its reduced lactose concentration renders it a viable alternative for individuals with lactose malabsorption, thereby increasing its appeal among health-oriented and lactose-intolerant consumer segments [7]. Additionally, its sensory attributes, particularly flavor, mouthfeel, and textural properties, are critical determinants of consumer acceptance and market success [8].

Despite its numerous nutritional advantages, yogurt lacks dietary fiber, which limits its functional capacity as a comprehensive health-promoting food. To overcome this limitation, researchers have focused on the fortification yogurt with plant-based fibers [9] and bioactive compounds [10] to improve its physicochemical and functional properties. Key ingredients such as rice bran, honey, and ginger extract have been emerged as promising candidates due to their distinct nutritional and bioactive profiles. Rice bran, a nutrient-rich byproduct of rice milling processes [11], is a rich source of essential fatty acids, dietary fiber, protein, minerals, and vitamins [12]. It is known for its anti-cancer and hypocholesterolemic effects [13]. Honey provides essential micronutrients and polyphenolic compounds [14], with proven anti-inflammatory properties which may mitigate the risk of inflammatory diseases, including cardiovascular disease, diabetes mellitus, arthritis, and neurological disorders [15]. Ginger extract, derived from Zingiber officinale, contains a range of bioactive compounds, such as essential oils, phenolic compounds, flavonoids, carbohydrates, proteins, saponins, steroids, and terpenoids [16]. These phytochemicals have been demonstrated to confer therapeutic benefits, supporting cardiovascular, respiratory and neurological health [17].

The incorporation of honey, ginger extract, and rice bran into Greek-style yogurt presents a novel formulation strategy that combines a diverse array of nutrients and bioactive phytochemicals with potential health-promoting properties. This study aims to bridge the gap in research by investigating the effects of these fortifications on a colorimetric parameters (redness/greenness (a*), yellowness/blueness (b*), lightness (L*), chroma (C*), hue angle (h°), and whiteness index (WI) and multiple sensory attributes of Greek yogurt. By analyzing the interaction of these ingredients, this research endeavors to provide valuable insights into their applications in developing functional dairy products.

2-Materials and methods

2.1 Preparation of Ginger extract

Ginger extract was prepared by maceration, wherein 200 grams of ground ginger powder was immersed in 800 mL of 96% (v/v) ethanol and maintained at ambient temperature (~25°C) for 24 hours. The mixture was then filtered using Whatman No. 1 filter paper. To eliminate residual ethanol and ensure product safety, the filtrate was subjected to rotary vacuum evaporation at 40°C for 2 hours. The resulting concentrated extract was reconstituted with distilled water to obtain final concentrations of 1% and 2% (w/v) for incorporation into the yogurt matrix [18].

2.2 Yogurt preparation

Greek-style yogurt was prepared using standardized bovine milk, which was pasteurized at 90–95°C for 5 minutes to ensure microbial safety and protein denaturation. The milk was then cooled to the fermentation temperature range of 40–45°C. At this stage, a mixture consisting of 3% starter culture (Biotec Fermenti SRL Co, Italy), 5% non-fat dry milk, and various additives is added. The resulting mixture is then incubated at 40- 45°C for three hours before being cooled for 12 hours at 5°C. Finally, straining is carried out at 5°C for 12 hours to obtain the characteristic thick consistency of Greek yogurt. The final product was stored under refrigerated conditions at a temperature of 4±2°C until further analysis [19].

2.3 Treatments

In this study, honey, ginger extract, and rice bran were incorporated into Greek yogurt formulations at concentrations of 3% and 6% (w/w), 1% and 2% (v/w), and 3% and 6% (w/w), respectively. Detailed data on the treatments are shown in Table 1.

Table 1- Experimental design for Greek yogurt formulations fortified with honey, ginger extract, and rice bran

Treatment	Honey percentage (weight/weight)	Ginger extract percentage (volume/weight)	Rice bran percentage (weight/weight)
Control	-	-	-
T_1	3	1	3
T_2	3	2	6
T_3	6	1	3
T_4	6	2	3
T5	6	1	6
T6	6	2	6

2.4 Colorimetric and Sensory Analyses

Colorimetric measurements (a*, b*, and L*) were performed using a digital colorimeter (model CR-400, Konica Minolta, Japan), equipped with a DP-400 data processor. The measurements were performed under standardized illumination and calibrated using a white reference plate prior to analysis. Derived color parameters were calculated according to the following equations:

Chroma (C*) = $\sqrt{(a^{*2} + b^{*2})}$

Hue Angle (h°) = $\tan^{-1}$ (b*/a*). Angles were adjusted based on the coordinate quadrant of a* and b* values.

Whiteness Index (WI) = 100 - $\sqrt{[(100 - L*)^2 + a^{*2} + b^{*2}]}$

Colorimetric evaluations were conducted for each of the seven treatments in triplicate.

Sensory evaluation was conducted using a 5-point hedonic scale by 15 panelists (male and female) aged 20-23 years. Yogurt samples (approximately 30 g) were served at 4°C in randomized order using three-digit codes. Panelists were provided with distilled water as palate cleansers between samples. The sensory attributes were assessed using the following scale: "Dislike very much" (1), "Dislike" (2), " Neither like nor dislike" (3), "Like" (4), and "Like very much" [20].

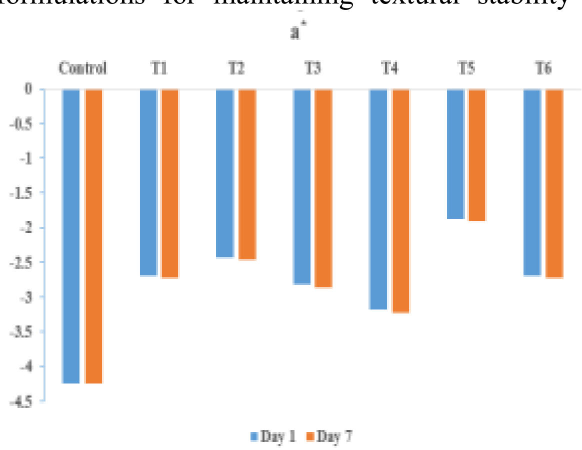
2.5 Statistical Analysis

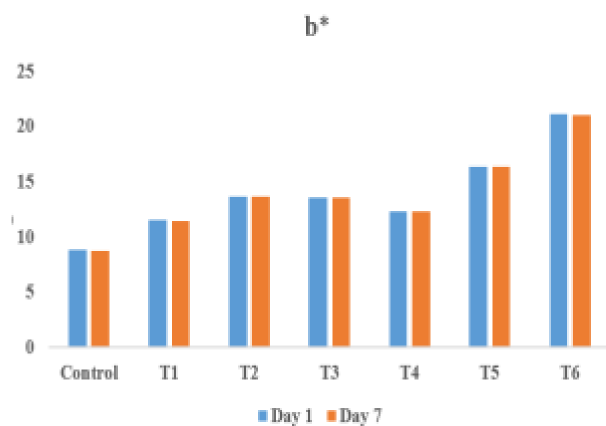
All experimental data were analyzed using multifactor ANOVA with SPSS statistical software (Version 26.0). Differences among treatment means were determined using Duncan's multiple range test at a 5% significance level ($p < 0.05$). Results are expressed as mean ± standard deviation (SD).

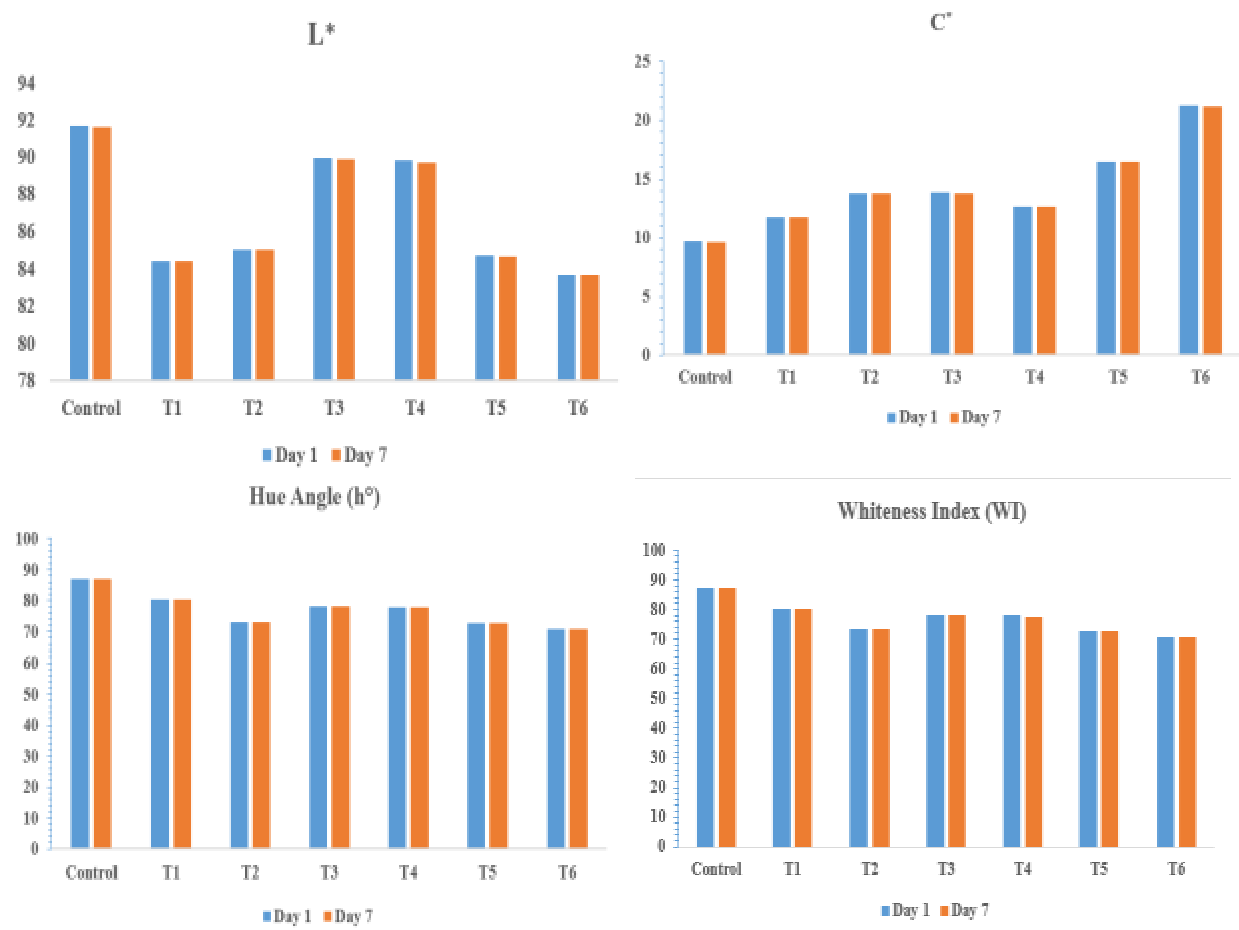
3-Results and Discussion

Color is a critical quality attribute in food products and plays a pivotal role in influencing consumer perception and acceptance [21]. The colorimetric parameters of the Greek yogurt samples are presented in Figure 1 for day 1 and day 7 of refrigerated storage. A significant difference was observed in the a* values among the investigated treatments on both the first and seventh days of storage ($p< 0.05$). A significant difference was observed between the control treatment and all other treatments on both days. The control sample exhibited the lowest a* value. No statistically significant change ($p > 0.05$) in a* values was detected over the storage period, indicating the stability of red-green chromatic components during storage. It seems that a* value is affected by the concentration of the incorporated additives. Specifically, formulations containing higher levels of honey and rice bran demonstrated decreased greenness and enhanced redness. OM et al. (2021) reported that the incorporation of African black pepper extract, turmeric, and cloves into yogurt did not significantly affect its redness, yellowness, or brightness intensity [21]. Conversely, Adnan et al. (2022) reported that fortifying goat milk yogurt with honey at concentrations of 2%, 4%, 6%, and 8% significantly increased the redness of the samples [22], which aligns with the colorimetric trends observed in the present study. The b* values exhibited a marked increase in the fortified treatments compared to the control sample. Among all formulations, the treatment 6 showed the highest b* value. This significant enhancement in yellowness can be attributed to the elevated concentrations of honey and rice bran, both of which are rich sources of carotenoids and other natural pigments. The b* values indicate that the incorporation of these additives imparted a deeper yellow hue to the product, potentially enhancing its sensory characteristics and consumer appeal. Furthermore, the minimal variations observed between day 1 and day 7 suggest that the yellow coloration induced by fortification remained stable throughout the storage period. Previous studies have similarly reported that the incorporation of honey [23], ginger [24], and rice bran [25] into yogurt formulations significantly enhances product yellowness. This effect has been partially attributed to the presence of natural pigments and, in some cases, to Maillard reaction products formed during processing [26]. A significant difference ($p < 0.05$) was observed in the L* values of the treatments on both the first and seventh days of storage. On both days, the control exhibited the highest L* values, indicating greater brightness compared to the fortified samples. The consistency of L* values between day 1 and day 7 suggests that the overall brightness of the yogurt remained stable during short-term storage. This observation is consistent with previous findings, in which a reduction in brightness was associated with the incorporation of rice bran into yogurt formulations [27]. The derived colorimetric parameter chroma (C*), which reflects color intensity or saturation, followed a similar trend, with T٦ recording the highest value, significantly greater than that of the control. This indicates that fortification, particularly with elevated concentrations of honey and rice bran, enhances color intensity and saturation in Greek yogurt. Consequently, the whiteness index (WI) was greatest in the control sample and decreased significantly in fortified treatments, with T6 showing the lowest WI, indicating a pronounced deviation from whiteness. Furthermore, the hue angle (h°) decreased significantly in fortified samples, shifting from the control's hue (~115°, corresponding to a yellow–red quadrant) toward a more distinct yellow hue (~97° for T5 and T6). No significant variations ($p > 0.05$) were observed in any color parameters during storage, suggesting that the fortified yogurts exhibited good color stability throughout short-term refrigerated storage. Several studies have investigated the impact of fortification on the colorimetric parameters of yogurt, including chroma, whiteness index, and hue angle (). Yogurt fortified with papaya peel powder exhibited significant changes in color parameters, including L*, a*, b*, C*, h°, and total color difference [28]. The incorporation of monk fruit sweetener in camel milk yogurt significantly influenced a*, b*, C*, and h° values. Control samples had lower b* and C* values and higher h° values compared to samples with higher concentrations of monk fruit sweetener [29].

The results of the Duncan's test for the sensory evaluation are presented in Table 2. Sensory evaluation conducted on the seventh day of storage revealed significant differences ($p < 0.05$) among the treatments in key sensory attributes, including overall acceptability, taste, and color. The control sample achieved the highest overall acceptability score (4.50), which was significantly greater than those of treatments 1 and 2. In contrast, treatments 4 and 5 exhibited scores that were not significantly different from the control group ($p > 0.05$). Taste ratings followed a similar trend to overall acceptability. The treatments 1, 2 and 3 recorded significantly lower scores ($p < 0.05$) compared to the control, whereas treatment 4 attained taste scores that were not significantly different from the control ($p > 0.05$). These findings imply that increasing the honey concentration in the yogurt formulation can mitigate the potential adverse effects on taste that may arise from the inclusion of ginger extract and rice bran. The color evaluation also revealed significant differences among treatments ($p < 0.05$). The control sample and treatment 1 exhibited the highest rate of color acceptance scores, indicating that higher consumer preference was associated with formulations containing lower levels of honey, ginger extract, and rice bran. Previous studies have similarly reported that the incorporation of rice bran may reduce brightness and alter the visual appearance in yogurt formulations, thereby affecting the color perception and acceptance [25]. In contrast, consistency did not differ significantly among treatments ($p > 0.05$). Consistency ratings remained within a narrow range, and texture scores showed similar uniformity across all formulations. This stability suggests that, while the fortification influenced the visual and gustatory properties of the yogurt, it had minimal impact on its structural integrity or aromatic profile, thereby supporting the suitability of these formulations for maintaining textural stability during storage. The findings indicate that higher concentration of honey in the yogurt formulations exert a positive influence on overall acceptability and taste, demonstrating a direct correlation between sweetness intensity and consumer preference. This observation aligns with previous research, which reported that consumers exhibited a greater preference for sweetened yogurt containing varying concentrations of sucrose [30]. Previous studies have also shown that the incorporation of ginger essential oil in yogurt enhances key sensory attributes, including taste, viscosity, and texture (Azimi & Azimi, 2021). However, contrasting evidence exists; Aamir et al. (2023) reported that the addition of ginger essential oil did not significantly affect overall acceptability. Furthermore, Simon et al., (2018) indicated that the inclusion of ginger extract at concentrations of 1% and 1.5% improved yogurt acceptability [31]. These findings suggest that the formulation type, additive form, and concentration of ginger derivatives play a critical role in shaping sensory perception and consumer response.







Treatment 1: Yogurt with 3% honey (w/w), 1% ginger extract (v/w), and 3% rice bran (w/w); Treatment 2: Yogurt with 3% honey (w/w), 2% ginger extract (v/w), and 6% rice bran (w/w); Treatment 3: Yogurt with 6% honey (w/w), 1% ginger extract (v/w), and 3% rice bran (w/w); Treatment 4: Yogurt with 6% honey (w/w), 2% ginger extract (v/w), and 3% rice bran (w/w); Treatment 5: Yogurt with 6% honey (w/w), 1% ginger extract (v/w), and 6% rice bran (w/w); Treatment 6: Yogurt with 6% honey (w/w), 2% ginger extract (v/w), and 6% rice bran (w/w). A significant difference was observed between the control treatment and all other treatments on both days ($p<0.05$).

Figure 1- The color properties of the yogurt samples during storage

Table 2-Evaluation of the sensory properties of the treatments on the seventh day of storage

	Sensory properties					
Treatment	General acceptability	Consistency	Texture	Taste	Odor	Color
Control	4.500±0.547^{A}	4.833±0.408^{A}	4.666±0.516^{A}	4.833±0.408^{A}	5.000±0.000^{A}	5.000±0.000^{A}
T_1	3.166±1.329^{BC}	4.166±0.752^{A}	3.500±1.224^{B}	2.500±1.378^{BC}	3.833±0.983^{AB}	4.000±1.095^{AB}
T_2	2.600±0.894^{BCD}	4.400±0.894^{A}	4.400±0.894^{AB}	1.600±1.341^{CD}	4.400±0.894^{AB}	3.200±0.447^{B}
T_3	2.571±0.786^{BCD}	4.000±1.414^{A}	4.000±0.816^{AB}	2.142±1.214^{BC}	3.428±1.397^{BC}	3.714±0.951^{AB}
T_4	4.250±0.500^{A}	4.250±0.500^{A}	4.250±0.500^{AB}	4.250±0.500^{A}	3.750±0.957^{ABC}	3.750±1.258 ^{AB}
T5	4.000±0.816^{AB}	4.250±0.500^{A}	4.250±0.500^{AB}	3.500±1.732^{AB}	3.500±1.732^{ABC}	3.500±1.290^{AB}
T6	3.000±1.154^{BCD}	4.500±0.577^{A}	4.500±0.577^{AB}	3.250±0.957^{AB}	3.500±1.000^{ABC}	4.000±0.816^{AB}

Treatment 1: Yogurt with 3% honey (w/w), 1% ginger extract (v/w), and 3% rice bran (w/w); Treatment 2: Yogurt with 3% honey (w/w), 2% ginger extract (v/w), and 6% rice bran (w/w); Treatment 3: Yogurt with 6% honey (w/w), 1% ginger extract (v/w), and 3% rice bran (w/w); Treatment 4: Yogurt with 6% honey (w/w), 2% ginger extract (v/w), and 3% rice bran (w/w); Treatment 5: Yogurt with 6% honey (w/w), 1% ginger extract (v/w), and 6% rice bran (w/w); Treatment 6: Yogurt with 6% honey (w/w), 2% ginger extract (v/w), and 6% rice bran (w/w).
Capital letters indicate significant differences between treatments ($p<0.05$).

The acceptability of yogurt exhibited an inverse relationship with the level of rice bran incorporation, likely due to its distinctive aroma and textural attributes, which may be perceived as undesirable sensory characteristics by consumers [32]. Previous studies have reported that the addition of rice bran contributes to the development of a sour flavor profile, primarily resulting from the enzymatic degradation of rice bran carbohydrates and milk glucose by lactic acid bacteria. Moreover, an increase in the carbohydrate fraction of rice bran has been shown to further enhance acid production, thereby intensifying yogurt sourness [33]. Given that consumer preference generally favors sweet-flavored yogurts over sour variants[34], the strategic incorporation of natural sweeteners or flavor-modulating agents could serve as an effective approach to improve product palatability and market acceptance. It should be noted, however, that the present study employed a limited number of factor levels (two concentrations per ingredient), which prevents estimation of main effects and interactions cleanly. Future investigations should adopt multivariate optimization approaches to precisely determine the optimal inclusion levels of honey, ginger extract, and rice bran for achieving a balance between nutritional enhancement and sensory appeal.

4-Conclusion

The findings of this study underscore the pronounced influence of honey, ginger extract, and rice bran fortification on the colorimetric and sensory characteristics of Greek yogurt. Comprehensive color evaluation through chroma, hue angle, and whiteness index analyses provided an integrated understanding of color modification resulting from fortification. Significant differences were observed among treatments, where higher inclusion levels of honey and rice bran produced elevated a* (redness) and b* (yellowness) values, concomitant with decreased L* (lightness). These alterations are attributed to the presence of natural pigments, polyphenolic compounds, and potential Maillard reaction products formed during storage. The stability of color parameters throughout refrigerated storage indicates that the fortified yogurts retained their visual integrity over the short term. Sensory analysis revealed that samples fortified with higher concentrations of honey achieved superior overall acceptability and flavor scores, comparable to those of the control formulation. Conversely, treatments containing lower honey levels and higher rice bran concentrations exhibited diminished sensory ratings, particularly in taste and color perception. The observed inverse correlation between rice bran concentration and sensory acceptance suggests that excessive rice bran incorporation may adversely affect texture and aroma, potentially introducing undesirable attributes such as enhanced sourness. Future research should aim to optimize the concentration and interactive effects of honey, ginger extract, and rice bran in Greek yogurt formulations through advanced experimental designs, such as response surface methodology or factorial designs, incorporating additional factor levels to enhance both sensory quality and nutritional functionality. Furthermore, extending the storage duration and assessing changes in texture, viscosity, rheological behavior, and flavor profile would provide a more comprehensive understanding of the long-term stability of these fortified dairy products. In addition, elucidating the molecular and physicochemical mechanisms underlying colorimetric behavior and sensory perception could yield valuable insights for product formulation optimization and the development of next-generation functional dairy products.

Author Contributions

Conceptualization: Fatemeh Mohammadzadeh, Fatemeh Ghannadiasl; Methodology: Fatemeh Ghannadiasl, Bahram Fathi-Achachlouei; Intervention design: Fatemeh Mohammadzadeh; Data analysis: Fatemeh Ghannadiasl, Bahram Fathi-Achachlouei; Writing – original draft: Fatemeh Mohammadzadeh; Writing – Review and editing: Fatemeh Ghannadiasl

Data Availability

The data that support the findings of this study are available on request from the corresponding author.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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مقاله علمی_پژوهشی

غنی‌سازی ماست یونانی با عسل، عصاره زنجبیل و سبوس برنج: تأثیر بر ویژگی‌های رنگ‌سنجی و حسی در طول نگهداری

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چکیده

این مطالعه با هدف ارزیابی تأثیر غنی‌سازی ماست یونانی با عسل (۳ ٪ و ٦٪ وزنی/وزنی)، عصاره زنجبیل (۱٪ و ۲٪ حجمی/وزنی)، و سبوس برنج (۳ ٪ و ٦٪ وزنی/وزنی) بر خصوصیات رنگ‌سنجی (شاخص روشنایی، شاخص قرمزی، شاخص زردی، کروما، زاویه هیو و شاخص سفیدی) و ویژگی‌های حسی آن (رنگ، بو، طعم، بافت، قوام و پذیرش کلی) در یک دوره نگهداری یک و هفت روزه انجام شد. نتایج آنالیز رنگ‌سنجی نشان‌دهنده افزایش معنادار در شاخص‌های قرمزی و زردی در فرمولاسیون‌های غنی شده نسبت به نمونه شاهد بود. بیشترین شدت قرمزی در نمونه حاوی ٦٪ عسل، ۱٪ عصاره زنجبیل و ٦٪ سبوس برنج مشاهده شد؛ علاوه بر این، رابطه معکوسی بین میزان سبوس برنج و روشنایی رنگ به دست آمد. ارزیابی حسی نشان داد که نمونه شاهد از پذیرش کلی بالاتری برخوردار بود، در حالی که فرمولاسیون‌هایی با ٦٪ عسل، ۲٪ عصاره زنجبیل و ۳ ٪ سبوس برنج در رتبه بعدی قرار داشت. افزایش غلظت عسل منجر به بهبود مقبولیت حسی گردید و مقدار بالاتر سبوس برنج تأثیر منفی بر پذیرش رنگ داشت. این یافته‌ها اطلاعات ارزشمندی را در مورد فرمولاسیون ماست یونانی غنی‌شده ارائه می‌کنند و بر اهمیت متعادل کردن خواص رنگ‌سنجی و ویژگی‌های حسی برای بهینه‌سازی پذیرش مصرف‌کننده تأکید می‌کنند. تحقیقات آتی می‌بایست با اصلاح نسبت مواد تشکیل دهنده، ارزیابی پایداری نگهداری بلندمدت و به کارگیری طرح‌های آزمایشی پیچیده‌تر با سطوح عاملی اضافی برای بهبود عملکرد و جذابیت محصولات ماست غنی شده تمرکز کنند.