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## CHANGES IN COLOR PARAMETERS OF HUMMUS ENRICHED WITH BLACK SEED (*NIGELLA SATIVA*) OIL DURING STORAGE

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**Abstract:** Hummus is a widely consumed plant-based spread whose popularity has continuously increased due to its favorable nutritional profile and potential for functional enrichment. In such products, visual appearance, particularly color, represents one of the first and most important quality attributes shaping consumer perception and acceptance. Changes in color may also serve as an indicator of physical and chemical processes occurring during storage, especially in semi-solid plant-based matrices such as hummus.

The aim of this study was to investigate the effect of different concentrations of *Nigella sativa* oil (NSO) on the color characteristics and color stability of hummus during storage. Five hummus formulations were prepared, including a control sample and samples containing 4, 6, 8, and 12% NSO, expressed as a proportion of the total lipid phase. All samples were stored at  $4 \pm 1$  °C for a period of 21 days.

Color parameters  $L^*$ ,  $a^*$ , and  $b^*$  were determined using image-based color analysis, with digital image processing followed by transformation from the RGB system to the CIE Lab color model. The total color difference ( $\Delta E$ ) was calculated in order to assess the visual perceptibility of color changes during storage. Statistical analysis revealed that storage time had a significant effect on all color parameters ( $p < 0.05$ ), whereas the effect of NSO concentration was limited, with statistically significant differences observed only for  $L^*$  values. During storage,  $L^*$  values initially decreased up to day 14, indicating slight darkening of the samples, followed by a pronounced increase on day 21. The  $a^*$  parameter progressively shifted toward more negative values, suggesting changes in the red–green balance, while  $b^*$  values showed a continuous increase, indicating enhanced yellowish tones. The  $\Delta E$  values increased throughout the storage period and reached an average value of 16.11 after 21 days, corresponding to a clearly perceptible visual color change. Higher NSO concentrations were associated with increased variability and higher  $\Delta E$  values, particularly in the sample containing 12% NSO.

Overall, the results indicate that the color of hummus remains relatively stable during the first 2 weeks of storage at  $4 \pm 1$  °C, after which visually noticeable changes occur. The incorporation of *Nigella sativa* oil contributes to the evolution of color during storage, highlighting the importance of optimizing the level of functional lipid enrichment in order to maintain the visual quality of hummus-based products.

**Keywords:** Hummus, *Nigella sativa* oil, color parameters, storage

### 1. INTRODUCTION

Hummus is a traditional plant-based spread prepared from chickpeas, tahini, olive oil, lemon juice, salt, oil, and spices, nutritionally balanced, sensorially acceptable, and aligned with recommendations for healthy nutrition (Goswami et al., 2025). Legumes represent a key group in healthy dietary patterns (Papanikolaou & Fulgoni, 2008), which, in addition to chickpeas, include alfalfa, clover, green beans, peas, peanuts, soybeans, dry beans and lentils (Rebello et al., 2014). As a chickpea-based food product, hummus provides significant amounts of plant proteins (18–23%), dietary fiber (12–15%), complex carbohydrates, minerals, and polyunsaturated fatty acids (Jukanti et al., 2012; Wallace et al., 2016).

Color represents an indicator of freshness, quality, and product stability, as it directly reflects the occurrence of chemical, biochemical, microbiological, and physical changes in the food matrix during processing and storage (Pathare et al., 2012). Instrumental colorimetry enables objective and reproducible monitoring of visual changes during processing and storage. In the food industry, the CIE  $L^*$ ,  $a^*$ ,  $b^*$  system is most widely applied, as it quantifies lightness ( $L^*$ ) and chromatic coordinates ( $a^*$ ,  $b^*$ ), and is suitable for complex and semi-solid matrices such as hummus (Dutta & Nath, 2023). In plant-based spreads, color is the result of interactions between the aqueous and lipid phases, the protein network, and natural bioactive compounds, and is sensitive to small changes in formulation (MacDougall, 2010; Kiciak et al., 2025). Moderate modifications in the composition of hummus may cause statistically significant differences in perceived color and visual acceptability (Kiciak et al., 2025). The color

of chickpea-based products is also associated with the content of phenolic compounds, whereby darker seeds exhibit higher total phenolic content (Xu et al., 2007; Segev et al., 2010). The basic color of hummus results from pigments and phenolic compounds derived from chickpeas, which are concentrated in the seed coat, with significant differences between darker and lighter varieties. Negative correlations between lightness ( $L^*$ ) and phenolic content ( $r \approx -0.79$ ) indicate that colorimetric parameters may serve as indirect markers of the nutritional–functional potential of the product (Xu et al., 2007; Segev et al., 2010). Colorimetric properties of foods also depend on matrix structure, light scattering, particle size, and interactions among components (MacDougall, 2010). The pigments responsible for the color of food products are influenced by changes in pH during processing, which may initiate enzymatic and non-enzymatic reactions (Andrés-Bello, 2013). In hummus, in addition to pH value, color is influenced by water activity and oxidative processes, which are interconnected and directly dependent on composition and storage conditions (Yamani & Mehryar, 2011). Fresh hummus, with pH values around 4.8–5.3 and high water activity ( $a_w > 0.96$ ), represents an unstable system in which physicochemical and microbiological changes may be indirectly reflected in color and visual quality (Shahein et al., 2025). Martínez-Zamora et al. (2023) reported visually detectable changes for consumers ( $\Delta E$  values of 2.4–7.7) following the application of different technological treatments, combined with variations in hummus composition (Martínez-Zamora et al., 2023). The lipid phase plays a significant role in defining colorimetric properties, whereby oils rich in bioactive compounds and pigments can modify lightness and chromatic coordinates of the final product (Cheikh-Rouhou et al., 2007). Changes in the  $L^*$ ,  $a^*$ , and  $b^*$  parameters of *Nigella sativa* oil are strongly correlated with oxidative stability and peroxide value, which emphasizes the role of color as a functional indicator and not only a visual attribute (Arslan & Acar, 2024). The aim of this research is to investigate the effect of formulation and storage time on the colorimetric properties of hummus enriched with *Nigella sativa* oil.

## 2. MATERIALS AND METHODS

Raw chickpea grains (*Cicer arietinum* L.) were used as the main raw material for the preparation of hummus, along with tahini, salt, apple vinegar, the liquid obtained from cooking the chickpeas (aquafaba), and cold-pressed olive oil and black seed oil in appropriate proportions.

### Hummus preparation

The grains were previously soaked in water and then cooked until achieving appropriate softness. Hummus was prepared by mechanical homogenization of the cooked chickpea grains with the remaining ingredients of the formulation. For the purposes of the study, five different hummus formulations were prepared, differing in the content of black seed oil. Sample 1(s1), was prepared as a control sample, without the addition of black seed oil. Sample 2(s2) contained 4% black seed oil, sample 3(s3) contained 6%, sample 4(s4) contained 8%, and sample 5(s5) contained 12% black seed oil, with the percentages expressed as a proportion of the total lipid phase. The remaining ingredients were added in identical amounts in all formulations.

After preparation, the samples were packed in glass jars, pasteurized at 60 °C for 30 min, and then stored at a controlled temperature of  $4 \pm 1$  °C. Changes in the color of the hummus were monitored over a period of 21 days. During the experimental period, the samples were kept under identical conditions, without additional manipulation except for the purposes of analysis (Delinikolova & Jankuloska, 2025).

### Color Measurement

Colorimetric analyses were carried out at four time points at 7-day intervals. Color determination was performed using computer analysis of digital images (Lukinac Čačić, 2012; Nakov et al., 2019).

The methodology included several consecutive phases: digitization of the examined samples, processing and analysis of the digital images using appropriate computer software, and transformation of the obtained values from the RGB color system into the CIE Lab\* model. The parameters  $L^*$  (lightness),  $a^*$  (red–green component), and  $b^*$  (yellow–blue component) were used for objective color evaluation. For each sample, three independent measurements were performed, and the total color difference ( $\Delta E^*$ ) was calculated according to the following formula:

$$\Delta E = \sqrt{(L - L_0)^2 + (b - b_0)^2 + (a - a_0)^2}$$

where:  $\Delta E$  represents the total color difference, ( $L^*$ ,  $a^*$ ,  $b^*$ ) measured sample values and ( $L^*_0$ ,  $a^*_0$ ,  $b^*_0$ ) the corresponding values of the reference (control) sample.

### Statistical analysis

Statistical analysis included descriptive statistics and inferential tests. Normality of distribution was assessed using the Shapiro–Wilk test, and in cases of deviation from normal distribution, non-parametric tests were applied:

Kruskal–Wallis (by sample), Friedman (by days), and the Wilcoxon Signed-Rank test for post-hoc analyses. All analyses were performed in triplicate. Statistical significance was accepted at  $p < 0.05$ .

### 3. RESULTS AND DISCUSSIONS

The overall descriptive analysis showed that hummus is characterized by high lightness, with a mean  $L^*$  value of  $85.29 \pm 3.15$ , while the median (84.90) was close to the mean, indicating a relatively symmetric distribution. The  $a^*$  parameter had a negative mean value ( $-3.19 \pm 0.92$ ), indicating dominance of the green component, whereas  $b^*$  showed higher values ( $41.66 \pm 5.62$ ), characteristic of a pronounced yellow hue of hummus. The total color difference ( $\Delta E^*$ ) ranged over a wide interval, from 0.24 to 20.70, with an average value of 6.97, confirming that visually perceptible color changes occurred in some samples and storage periods (Table 1).

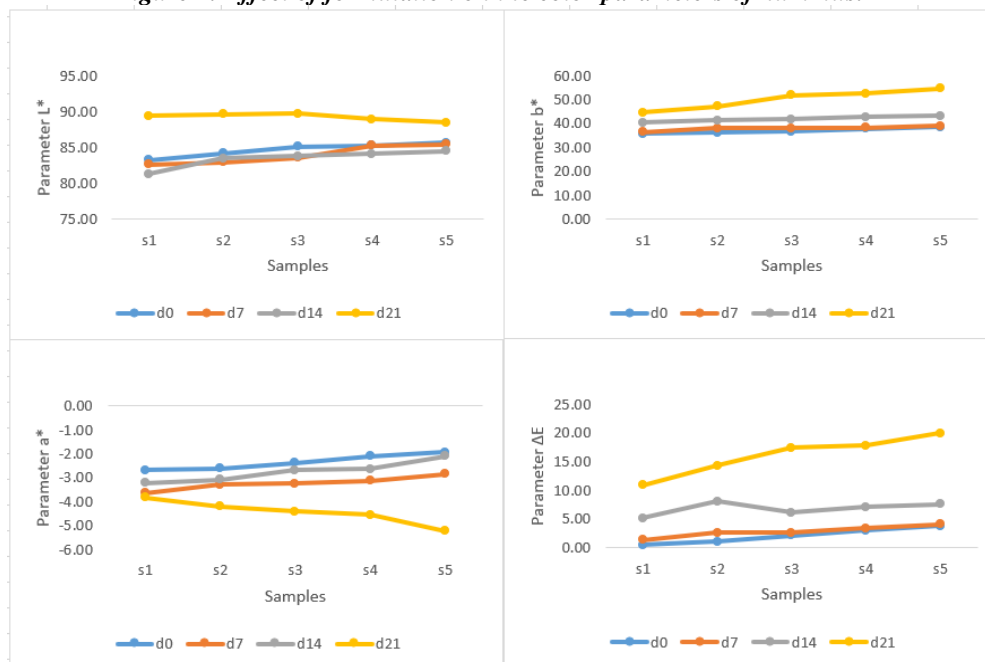
**Table 1. Descriptive statistics of CIE Lab color parameters of hummus samples.**

Measure	$L^*$	$a^*$	$b^*$	$\Delta E$
Mean	85.294	-3.191	41.659	6.968
Median	84.899	-3.049	39.870	4.731
Variance	9.917	0.853	31.620	35.612
SD	3.149	0.924	5.623	5.968
Minimum	76.452	-5.318	35.404	0.240
Maximum	96.904	-1.740	55.471	20.703
Range	20.453	3.579	20.067	20.463

Source: author’s research

The analysis of distribution at the overall level showed a statistically significant deviation from normal distribution for all parameters:  $L^*$  ( $W = 0.918, p = 0.001$ ),  $a^*$  ( $W = 0.950, p = 0.016$ ),  $b^*$  ( $W = 0.853, p < 0.001$ ), and  $\Delta E$  ( $W = 0.845, p < 0.001$ ). At the level of individual samples, deviation from normality for the  $L^*$  parameter was determined in s1, s3, s4, and s5 ( $p < 0.05$ ); for the  $a^*$  parameter in s5 ( $p = 0.005$ ); the  $b^*$  parameter showed deviation from normal distribution in all samples ( $p < 0.05$ ); for  $\Delta E$ , normality was violated in most samples, with the exception of s2 ( $p = 0.104$ ). Considering that deviation from normal distribution was observed for most parameters and samples, further analysis was performed using non-parametric statistical tests.

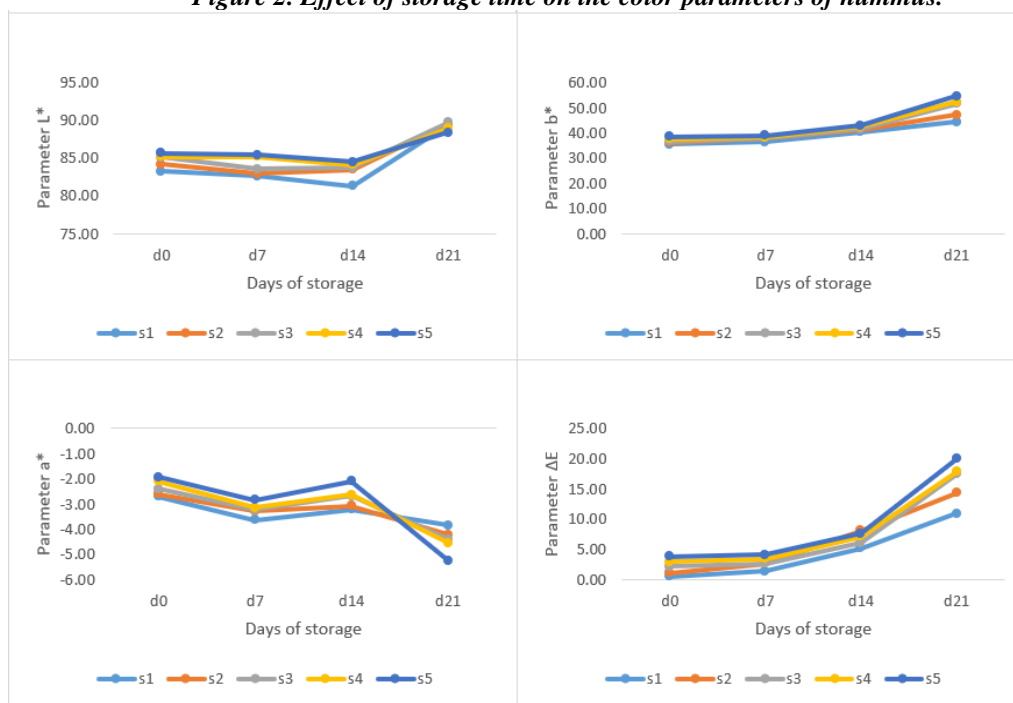
**Figure 1. Effect of formulation on the color parameters of hummus.**



Source: author’s research

The analysis by sample showed a slight increase in lightness ( $L^*$ ) from s1 (84.11) to s5 (85.98), accompanied by a decrease in variability, i.e., greater color homogeneity in samples with a higher oil concentration (Figure 1). The Kruskal–Wallis test showed a statistically significant difference among formulations only for  $L^*$  ( $p = 0.027$ ), while for  $a^*$  ( $p = 0.418$ ),  $b^*$  ( $p = 0.205$ ), and  $\Delta E$  ( $p = 0.190$ ) no significant differences were determined, indicating that formulation has a limited effect on chromatic coordinates and the total color change.

**Figure 2. Effect of storage time on the color parameters of hummus.**



Source: author's research

When observed from the aspect of the days on which the colorimetric parameters were measured, the analysis also shows unambiguous trends, with a pronounced positive trend being evident, that is, an increase in the parameters from the first to the 21st day (Figure 2).

The average  $L^*$  values decreased from 84.66 (d0) to 83.40 (d14), and then increased to 89.18 (d21). The  $a^*$  parameter became more negative over time in all samples, from  $-2.34$  (d0) to  $-4.45$  (d21), with a minimum value of  $-5.24$  in s5 on day 21, showing a pronounced shift toward green hues, while the  $b^*$  parameter showed a continuous increase, from 36.85 to 50.06, suggesting an increase in yellowish tones. At the same time,  $\Delta E^*$  showed a clear increasing trend, from 2.10 reaching an average value of 16.11 on day 21, representing a visually clearly perceptible change for the consumer.

The Friedman test confirmed that differences in all colorimetric parameters were statistically significant depending on the day of measurement ( $p < 0.05$ ), namely for  $L^*$  ( $\chi^2 = 13.56$ ,  $df = 3$ ,  $p = 0.004$ ),  $a^*$  ( $p = 0.002$ ),  $b^*$  ( $p = 0.002$ ), and  $\Delta E^*$  ( $p = 0.002$ ), indicating significant changes in the color of hummus during storage. Additional analysis using the Wilcoxon rank test showed that almost all pairs of days were also statistically different, with the exception of  $L^*$  between day 7 and day 14 ( $p = 0.225$ ), indicating a short-term stabilization of lightness during that period.

#### 4. CONCLUSION

The results of the colorimetric analysis of chickpea hummus show clear trends in color changes over time, accompanied by a decrease in lightness ( $L^*$ ) during the first two weeks and a significant increase in the third week; an increase in redness (lower, that is, more negative  $a^*$  values over time); an increase in yellowness ( $b^*$ ); and a significant increase in the total color change ( $\Delta E$ ). Such patterns indicate oxidation and degradation of hummus during storage, with the most pronounced changes observed after three weeks (measurement on day 21). The increase in  $\Delta E$  after three weeks indicates a visible color change in all samples, most pronounced in s5, which darkens and yellows most rapidly, that is, it is more pronounced in samples with a higher concentration of black seed oil.

These data suggest a limited shelf life of two weeks for maintaining the original color. In the formulation of hummus enriched with functional oils, it is necessary to carefully optimize their concentration in order to achieve a balance between nutritional added value and preservation of visual quality during storage.

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