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Effect of *A. bisporus* Mushroom Processing on Qualitative, Nutritional and Quality Characteristics

MEHRDAD JAFARPOUR[1,2], MEHRNOOSH KAHVAEI[2], DAVOUD AHMADI[3]

1- Associate Professor, Department of Horticultural Sciences, Faculty of Agriculture, Islamic Azad University, Isfahan (Khorasgan) Branch

2- Edible and Medicinal Mushroom Research Center, Islamic Azad University, Isfahan (Khorasgan) Branch

3-MSc., Department of Agriculture and Food Security, Newcastle University, Newcastle upon Tyne, United Kingdom

[*] Corresponding author E-mail: mehrdad.jafarpour@gmail.com

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ABSTRACT

The processing of agricultural products or processing activities is crucial in developing the fruit and vegetable industry, increasing the marketability of fresh produce, and reducing post-harvest waste. This study evaluated the effect of different processing and drying methods (Such as salting, canning, infrared, and hot air) on the quality characteristics of *A. bisporus* mushroom. The maximum shrinkage ratio was achieved through the infrared treatment, with a value of 6.66 mm, while the lowest was obtained in the salting treatment, with a value of 1.17 mm. The highest fat content was observed in hot air treatment at 5.33%, while the lowest amount was obtained in the canning and salting treatments at 0.66% and 1%, respectively. The highest browning index was reported in the canning treatment, while the lowest was in the infrared and hot air treatments. The highest color change was found in the canning treatment, with a value of 21.45, while the lowest rate was observed in the infrared and hot air treatments, with values of 6.63 and 10.22, respectively. The highest color index of L* was observed in the control, infrared, and hot air treatments. However, the lowest amount was illustrated in the canning treatment. The highest color index of a* was observed in the canning treatment, with a rate of 12.93, while the lowest was found in the infrared, hot air, and control treatments. The highest color index of b* was observed in the salting and canning treatments. On the contrary, the lowest amount was indicated through the control, infrared, and hot air treatments. In general, the study results revealed that the infrared and hot air treatments significantly impacted the improvement of the color indices. Also, the canning treatment preserved the fat content and prevented its excessive oxidation in the A. *bisporus* mushrooms.

Keywords: Infrared, Canning, Shrinkage, Color indices, Amino acids

INTRODUCTION

Fresh vegetables and fruits contain high amount of moisture, with approximately 80% of their weight being water, creating ideal circumstances for microbiological and enzyme activities that contribute to rapid spoilage during the post-harvest period (Mat Desa *et al*., 2015). Food spoilage has long been a concern for humans as it can lead to various diseases, even death, and financial losses (Joardder *et al*., 2018). To address this issue, humans have developed methods to slow down the food spoilage process and extend the storage time of food (Biernacka *et al*., 2022). Initially, by understanding some of the causes of food spoilage, such as temperature, the natural factors were used to prolong the storage time of the food (Cavusoglu *et al*., 2015). However, with the advancements in knowledge and industry, these methods have constantly evolved to become more complex and efficient. Processing of agricultural products or processing activities is crucial in the development of fruit and vegetable industry, increasing the marketability of new products and reducing post-harvest waste (Krzykowski *et al*., 2023). Due to the growing trend of population, food supply has become a major concern for the world. Moreover, population growth and rising costs of food, particularly high-quality protein sources, have further emphasized the importance of agricultural food resources (Zhao *et al*., 2020). Today, edible mushroom cultivation has become increasingly important worldwide, with significant progress being made in this sector. According to the Food and Agriculture Organization (FAO), global mushroom production reached about 11 million tons in 2020, with Iran contributing 180 thousand tons to this total (Fartash Naeimi *et al*., 2020).

High amount of moisture in the products plays a crucial role in their storage. Drying, as one of the conventional and old methods, is used to extend the shelf life of agricultural products (Hargoindigo and Fisour, 2019) by reducing the moisture in the foods, slowing down the microbial spoilage and chemical changes and subsequently, increasing the storage time as well as reducing the required space and weight (Tetteh *et al*., 2019). This process involves extracting existing water in a food through evaporation or sublimation using a thermal source under controlled and precise conditions (Bhatta *et al*., 2020). In order to prevent thermal and moisture stresses that could lead to quantitative and qualitative losses of the product, strict controls on the drying process are necessary (Wang *et al*., 2023).

Despite the important advantages of drying in the processing and preserving of agricultural and food products, using incorrect methods and applying unfavorable conditions can lead to

quality loss and decreased final product value, as well as increased time, money, and energy consumption. In fact, the biggest challenge of drying industry is to produce a high-quality product at a minimum cost (Hu *et al*., 2020). Thus, evaluating the consumed energy and quality of the final product is necessary to determine the optimal drying conditions for each product. The purpose of this Study the impact of different drying methods and conditions on the consumed energy in the drying process of various products are also important for researchers.

MATERIALS AND METHODS

Uniform *A. bisporus* mushrooms without any stain, disease, etc., were selected and transferred to the Edible and Medicinal Mushroom Research Center, Islamic Azad University, Isfahan (Khorasgan) Branch. Fresh mushrooms were stored in the fridge at 4 °C with a relative humidity of 95% prior to the test. The samples were washed with cold water to remove the sticky soil particles, dispose of compost residues on mushrooms, and reduce the microbial load. This step was done as fast as possible to prevent the absorption of extra water. Mushrooms were cut into 5±1 mm thick using a sharp steel knife after manually removing the extra water from the surface. Mushroom slices were placed on one layer of special steel trays and then transferred to the drying device.

Treatments / Hot air

The fruit body of the sliced *A. bisporus* mushroom (all 5000 grams) was placed on the steel trays. Then, the mushrooms were dried using the electric thermal drier at 55 °C for 4 hours so that the moisture content of the samples reached the moist base of 10 grams per 100 grams (Hu *et al*., 2020).

Infrared

The sample mushrooms were dried under the infrared rays at 35 °C with a short wavelength (Hu *et al*., 2021). The infrared lamps were placed in a row on the upper surface of the dryer chamber, emitting infrared radiation in the range of medium to short wavelengths (2.3-3 μm). The maximum power of each lamp was 450 watts, and the radiation efficiency was 70-80%. To ensure the uniform radiant heating, 6 IR lamps were turned on with a

maximum power of 1.2 kW. The distance between the infrared lamps and the trays containing the mushroom samples was 14 cm (Wang *et al*., 2015).

Canning

180 grams of *A. bisporus* mushroom were placed in 300cm^3 glass containers, sealed, and sterilized with 100 cm^3 of hot solution containing 2% salt through aerated immersion. The sterilization process was as follows: increasing the temperature up to 100 °C for 5 minutes, increasing the temperature from 100 to 118 °C for 10 minutes, sterilizing at 118 to 121 °C for 12 minutes, and finally, cooling at 30 °C for 10 minutes. Then, the canned mushrooms were stored at 8-10 °C (Jawroska *et al*., 2011).

Salting

The sliced mushrooms were immersed in a 10% salt solution for 10 minutes (Workneh *et al*., 2014).

Measuring methods of the studied traitsFat

Fat content was calculated by extracting it from the sample using ether as a solvent in the Soxhlet Extractor device (Shams *et al*., 2022).

Shrinkage

The thickness and Thickness Shrinkage Ratio (S_d) of the dried mushrooms were analyzed using the Vernier Scale at 0.05 mm accuracy (Shanghai Nine Volume Hardware Tools Co., LTD, China). Then, based on Equation (1), the Shrinkage ratio was evaluated in *A. bisporus* mushrooms under considered treatments. In this Equation, d_t (mm) and d_0 are the diameter and thickness of the dried and fresh mushrooms, respectively (Wang *et al*., 2014).

Equation (1)

$$S_d = d_0 - d_t / d_0 \times 100$$

Color Indices Measurement

The color of samples was examined using a Hunterlab device after and before drying, and the color values were presented as L* (brightness), a* (redness), and b* (yellowness). Browning index (BI), which represents the purity of brown and is considered an essential factor of Browning, was measured based on Equation (4) (Jiang, 2013).

Equation (4): BI= 100- (x-0.31)/0.172

Moreover, the color change (ΔE) of the samples treated with fresh mushrooms was obtained using Equation (5) (Jiang, 2013).

Equation (5):

$\Delta E= [(L-97)^2 + (a-(-2))^2+ b^2]^{1/2}$

RESULTS

The effect of the studied treatments on the qualitative features of A. bisporus Mushroom

The data analysis of variance showed that the effect of treatment on the shrinkage of *A. bisporus* mushrooms was significant at the probability level of 1% (Table 1). Comparing the mean of data showed that the effect of the studied treatments on the shrinkage in *A. bisporus* mushroom was significant at a 5% probability level of Duncan's test, indicating the maximum shrinkage in Infrared ray treatment with a value of 6.66 mm, and the minimum shrinkage in salting treatment with the value of 1.17 mm. There was no statistically significant difference between canning and hot air treatments at the 5% probability level of Duncan's test (Figure 1).

Table 1. The results of variance analysis of the effect of studied treatments on quality characteristics of *A. bisporus* mushroom

		Mean Squares			
Sum of squares	Degree of freedom	Shrinkage	Fat content	BI	EΔ
Treatment	3	16.01**	13.57**	168.363**	956.76**
experimental error	8	0.42	0.07	455.65	32.84
Coefficient of variations %		14.07	11.18	24.96	24.26

**: significant at 1% probability level

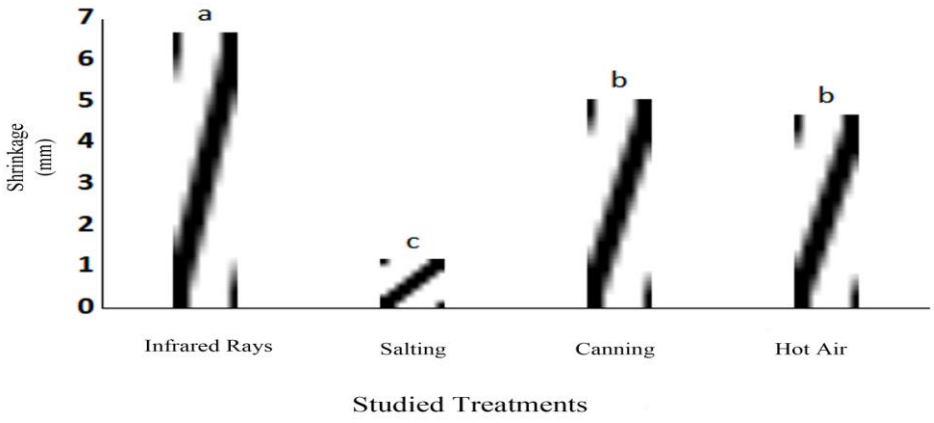

Figure 1. Comparison between the means- the effect of different treatments on the shrinkage of *A. bisporus* mushrooms. Means with at least one letter in common do not have a significant difference at 5% probability level of Duncan's test.

The data analysis of variance showed that effect of the treatment on the fat content in *A. bisporus* mushroom was significant at 1% probability level (Table 1). The comparison between the data indicated that the effect of the studied treatments on the amount of fat content in *A. bisporus* mushrooms was significant at 5% probability level of Duncan's test. This indicated a maximum fat of 5.33% in hot air treatment, while canning and salting treatments with the values of 0.66% and 1% were considered the minimum, respectively. Moreover, there was no significant difference between salting and canning treatments at 5% probability level of Duncan's test.

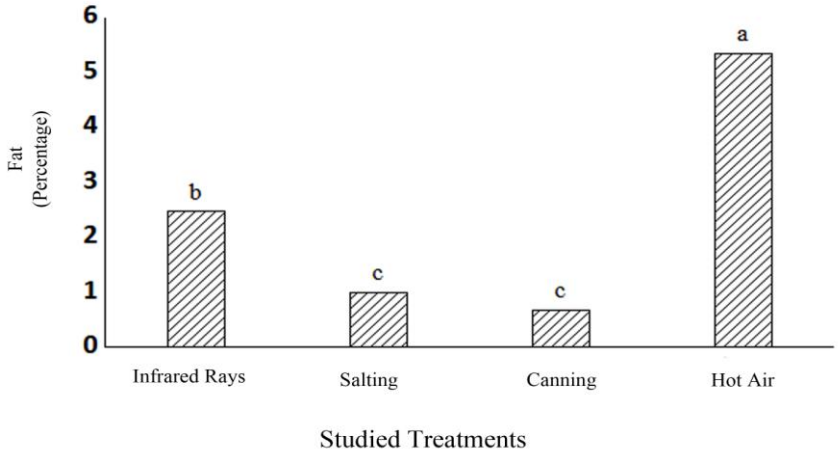

Figure 2. Comparison between the means- the effect of different treatments on the fat content of *A. bisporus* mushrooms. Means with at least one letter in common do not have significant difference at 5% probability level of Duncan's test.

Browning Index (BI)

Data analysis of variance indicated that the effect of the treatment on the Browning index in *A. bisporus* mushrooms was significant at 1% probability level (Table 1). Comparing the means of data showed a significant difference in the impact of different treatments on the Browning index in *A. bisporus* mushrooms at 5% probability level of Duncan's test. That is to say, the maximum Browning index was observed in canning treatment with the value of 140.66, while the minimum value was obtained in infrared rays and hot air treatments with the values of 25.79 and 32.42, respectively. There was no significant difference between the infrared rays and hot air treatments at 5% probability level of Duncan's test (Figure 3).

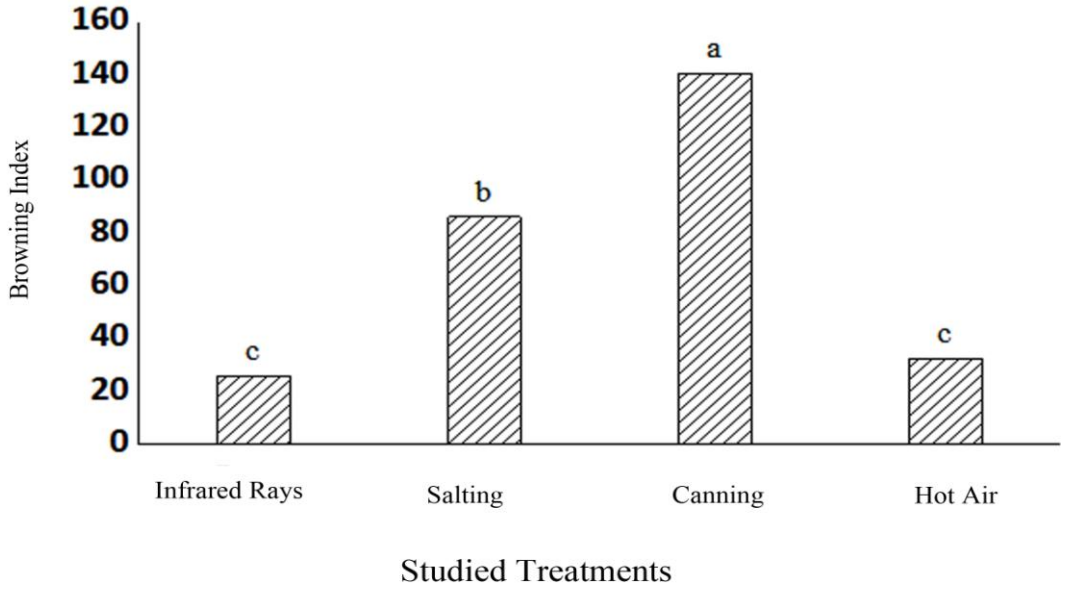

Figure 3. Comparison between the means- the effect of different treatments on the Browning index in *A. bisporus* mushrooms. Means with at least one letter in common do not have significant difference at 5% probability level of Duncan's test.

Color Change (ΔE)

The data analysis of variance revealed that effect of the treatment on the color change in *A. bisporus* mushrooms was significant at 1% probability level (Table 1). Comparing the means of the data indicated that effect of the studied treatments on the color change in *A. bisporus* mushrooms was significant at 5% probability level of Duncan's test. The maximum color change was observed in the canning treatment with the value of 45.21, while the minimum color change was seen in infrared rays and hot air treatments with values of 6.63 and 10.22, respectively. Furthermore, there was no significant difference between the infrared rays and hot air treatments at a 5% probability level of Duncan's test (Figure 4).

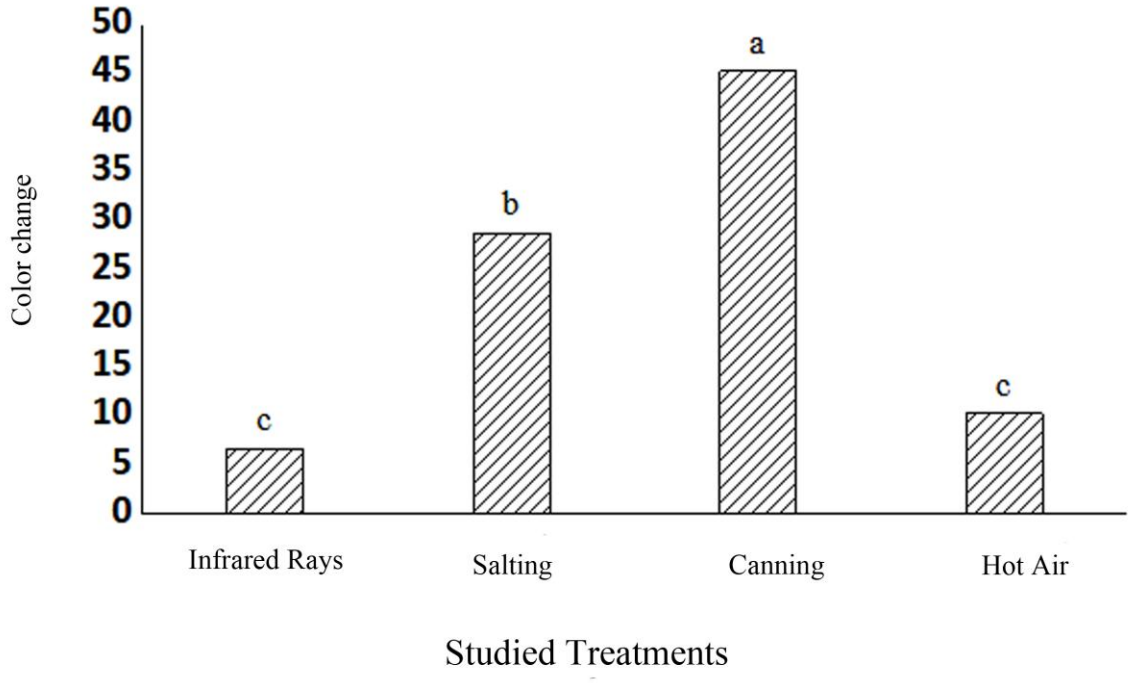

Figure 4. Comparison between the means- the effect of different treatments on the amount of color change in *A. bisporus* mushrooms. Means with at least one letter in common do not have significant difference at 5% probability level of Duncan's test.

*Color Index of L**

Data analysis of variance showed a significant difference in the impact of the treatment on a color index of L* in *A. bisporus* mushrooms at a 1% probability level (Table 2). The results of comparing the means of data represented that the effect of the studied treatments on the color index of L* in *A. bisporus* mushrooms was significant at a 5% probability level of Duncan's test. Also, the maximum color index of L* was control, infrared rays, and hot air treatments with the values of 79.26, 78.16, and 74.66, respectively, and there was no significant difference between these treatments at a 5% probability level of Duncan's test. The minimum value was observed in canning treatment with a value of 42.06 (Figure 5).

Table 2. Analysis of variance of the impact of the studied treatments on some quality features of *A. bisporus* mushrooms

		Mean Squared		
Sum of squares for error	Degree of freedom	L*	a*	b*
Treatment	4	74.241**	99.95**	191.30**
experimental error	10	13.19	2.71	29.05
Coefficient of variations %		5.39	24.32	22.45

**: significant at 1% probability level

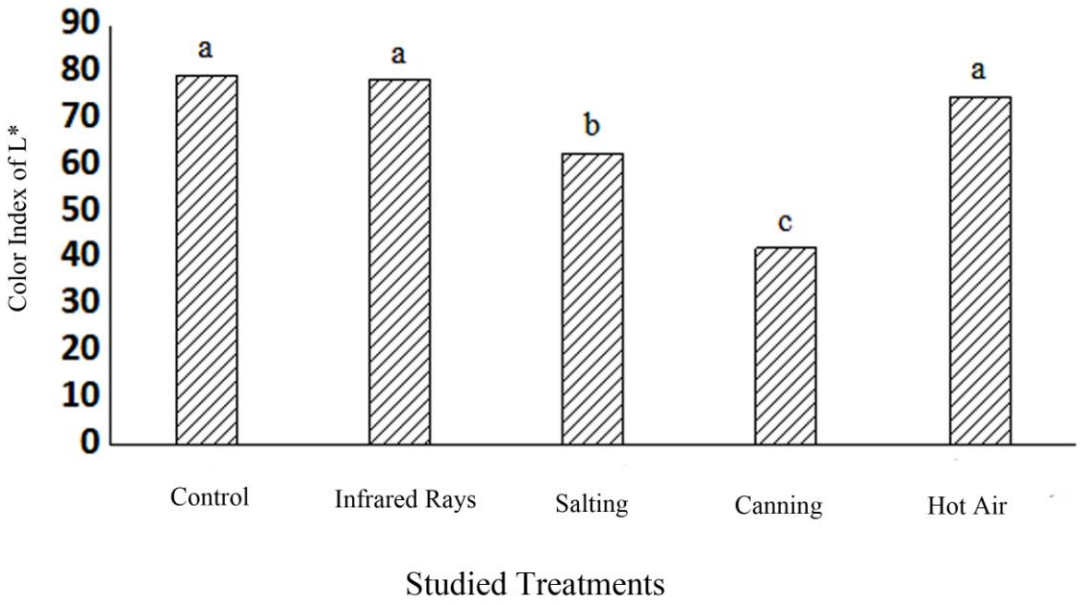

Figure 5. Comparison between the means- the effect of different treatments on the color index of L* in *A. bisporus* mushrooms. Means with at least one letter in common do not have a significant difference at 5% probability level of Duncan's test.

Color Index of a*

Data analysis of variance indicated a significant difference in the impact of the treatment on the color index of a* in *A. bisporus* mushrooms at a 1% probability level (Table 2). Comparison between the means of data revealed that the effect of the studied treatments on the color index of a* in *A. bisporus* mushroom was significant at a 5% probability level of Duncan's test. Moreover, the maximum value of the color index of a* was observed in the canning treatment with a value of 12.93, while the minimum value was seen in the infrared, hot air, and control group treatments with values of -0.86, 0.26, and 0.76, respectively; no statistically significant difference was observed at the 5% probability level of Duncan's test (Figure 6).

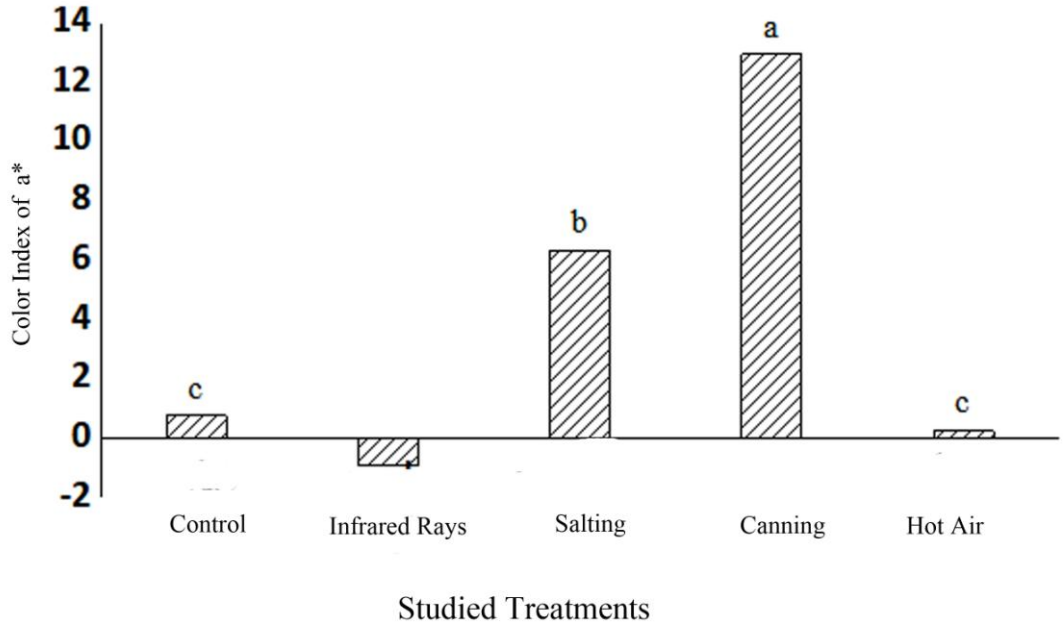

Figure 6. Comparison between the means- the effect of different treatments on the color index of a* in *A. bisporus* mushrooms. Means with at least one letter in common do not have significant difference at 5% probability level of Duncan's test.

Color index of b*

Data analysis of variance revealed a significant difference in the impact of the treatment on the color index of b* in *A. bisporus* mushrooms at a 1% probability level (Table 2). The results of comparing the means also showed that the impact of the studied treatments on the color index of b* was significant at a 5% probability level of Duncan's test. According to the results, the maximum value of the color index of b* was observed in the salting and canning treatments with values of 33.93 and 31.03, respectively. The minimum value was also detected in the control group, infrared, and hot air treatments with the values of 16.03, 18.02,

and 20.86, respectively, and there was no statistically significant difference in some of the treatments at a 5% probability level of Duncan's test (Figure 7).

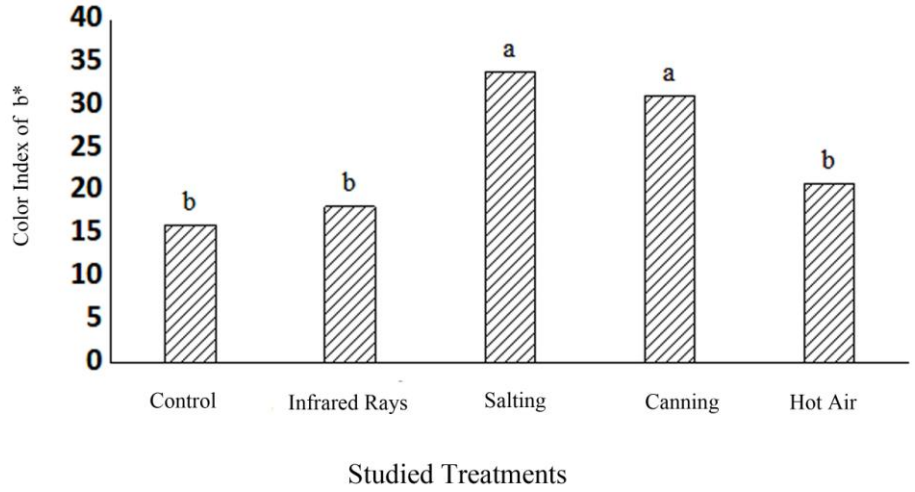

Figure 7. Comparison between the means- the effect of different treatments on the color index of b* in *A. bisporus* mushrooms. Means with at least one letter in common do not have a significant difference at 5% probability level of Duncan's test.

DISCUSSION AND CONCLUSION

The effect of different processing treatments on some of the quality characteristics of A. bisporus mushroom

Shrinkage Ratio

The research findings revealed that the highest shrinkage ratio occurred during infrared treatment, while the lowest shrinkage ratio was observed in salting treatment. The structural heterogeneity of fruits and vegetables poses a challenge in understanding the chemical-physical changes that occur during drying. Food is one of the most complex deformable materials due to its heterogeneous structure. The porous and hygroscopic nature of fruits and vegetables leads to increased shrinkage during the drying process, which is the common physical process observed in the drying process (Kumar *et al*., 2018). Shrinkage significantly impacts the mechanical and textural properties of fruits and vegetables. Above all, shrinkage is a significant factor that has a remarkable impact on the rate and kinetics of dryness. Therefore, food researchers emphasize the importance of considering shrinkage in predicting mass and heat transfer during the drying process (Aprajeeta *et al*., 2015). The shrinkage of foods depends on various factors, including material properties, mechanical

characteristics, and the drying process itself. Understanding porosity can aid in accurately predicting transfer phenomena and quality attributes during dryness (Karunasena *et al*., 2014). Cell destruction and texture shrinkage occur during the drying process. There is an accurate distinction between shrinkage and destruction. Shrinkage refers to the mass reduction of the product while destruction means the irreversible decomposition of cellular and textural structure. Structural changes at the cellular level during drying are driven by transfer phenomena. As previously mentioned, porosity and shrinkage during the dryness affect the transfer process and other quality characteristics (Gulati *et al*., 2015).

In the initial drying stage, mass shrinkage is primarily due to the loss of water content. However, shrinkage also occurs in subsequent drying stages, resulting from the pressure inside the cells (Mahiuddin *et al*., 2018). Decreased turgor pressure results from transferring a significant amount of water out of the cells in the final phase of drying. The resulting tension is due to the moisture gradient during drying, while thermal tension is more pronounced in the beginning stages (Llave *et al*., 2016). In other words, when drying begins, the temperature gradient within the sample is significant, leading to thermal tension. As drying progresses, the temperature gradient decreases, having no effect on the shrinkage of content. Ultimately, the entire sample reaches a stable temperature close to that of the drier (Joardder *et al*., 2015) where the heat transfers to the surface moisture to evaporate. Therefore, the tension caused by moisture gradient is one of the leading causes of shrinkage during drying (Mercier *et al*., 2011).

The highest shrinkage ratio in the texture of *A. bisporus* mushroom was observed with the infrared treatment, likely due to the low moisture content in this treatment, creating the hard porous shell. As a result, the moisture of the surface decreases rapidly, generating internal pressures within the texture, negatively impacting the shrinkage and creating significant porosity in the internal structure. Affected by other processing treatments, such as salting, the drying process of the product typically initiates at the outer layer, causing surface dryness and low porosity while preventing moisture extraction by forming a hard outer layer on the food. This effect is intensified by the high amount of sugar in agricultural products, further increasing the surface hardening. These findings are consistent with the results of research on the drying of lime (Kaveh *et al*., 2019) and garlic slices (Tao *et al*., 2018). Research results showed that the highest amount of fat was found in hot air treatment, while the lowest amount was observed in canning and salting treatments. There was a strong correlation between the fat content and the quality of the final processed product, and numerous studies were conducted on fat changes during the thermal process and canning. In the current research, the fat percentage in the *A. bisporus* mushroom dried with canning and salting treatments was significantly lower compared to drying through hot air, likely due to the retention of total organic matter ratios in each treatment (Yang *et al*., 2020). This means that as the protein percentage increased in canning and salting treatment, the percentage of other organic matter, including fat, decreased in the same ratio. While fat is a nutritional organic matter, it is one of the most influential factors in the lifespan of the product, which is due to fat oxidation during long-term storage (Li *et al*., 2015). It is apparent that the higher the fat percentage, the higher the possibility of oxidation, prompting efforts to reduce fat content

during production. In this study, the highest percentage was found in *A. bisporus* samples dried with hot air treatment. The elevated temperatures, due to the increase in protein denaturation and an increase in nonpolar amino acids in the side chain of the protein structure, led to more fat absorption by proteins, resulting in increased fat content in the sample (Yang *et al*., 2020).

Color indices

The research results indicated that the highest Browning index, color change, and color index of a* were observed in the canning treatment, while the lowest values were seen in infrared and hot air treatments. The highest color index of L* was found in the control group, infrared, and hot air treatments, with the lowest value in canning treatment. Maximum color index of b* was seen in salting and canning treatments, while the minimum was observed in the control group, infrared, and hot air treatments.

Undesirable color is a result of Browning reactions. Factors such as moisture, temperature, pH, and food compounds accelerate the Browning reactions and Maillard's non-enzymatic browning. Rapid browning typically occurs in the middle range of moisture content, decreasing with higher or lower moisture levels. Canning treatment was found to increase the Browning index of *A. bisporus* mushrooms (Chuensun *et al.*, 2020).

When stress occurs within the tissue of the product, cells may face obstacles in their movement path, leading to the combination of phenolic compounds, such as catechin and polyphenols, with polyphenol oxidase or phenol peroxidase. This process can be more pronounced in some areas, being darker than in other areas (Cavusoglu *et al*., 2021). Additionally, air bubbles in the product tissue can cause the transfer of the phenolic compounds to the vacuole or the cellular wall. Small amounts of phenolic compounds may also be present in the chromoplast, cytoplasm, and mitochondrion, contributing to uneven color patterns during enzymatic Browning (Huang *et al*., 2019).

Hot air and infrared treatments reduce the drying time by causing consecutive shrinkage and expansion, creating longer microscopic channels. This results in *A. bisporus* mushroom samples being exposed to high temperatures for a shorter period of time, preventing further degradation of pigments in the mushroom samples. Infrared radiation helps maintain the color properties in medicinal products like *A. bisporus* mushrooms by decreasing the drying time and limiting the time of enzymatic reactions of browning. Additionally, the optimal air flow positively impacts the color quality of product by reducing drying time (Ebadi *et al*., 2016). Kocabiyik *et al*. (2015) and Kantrong *et al*. (2014) reported similar results.

Color index b* indicates the range of changes from blue to yellow, and its increasing trend with salting and canning treatments shows the increase in yellowness over time (Shafeei *et al*., 2014). This increase in the yellowness can be attributed to reactions resulting in Browning. In mushroom samples processed by salting and canning treatments, the levels of redness and yellowness (a* and b*) increase due to reduced moisture content, explaining the non-enzymatic browning of samples. This process is more effective in low moisture conditions, which is why dry food is more susceptible to Browning. The changes in redness and brightness parameters are linked to enzymatic reactions of browning, where an increase in

the Browning index leads to decreased brightness and increased redness (Duan *et al*., 2022). The research findings align with studies conducted by Duan *et al*. (2022) and Cavusoglu *et al*. (2021) on Button mushrooms.

CONCLUSION

In general, the research findings revealed that infrared and hot air treatments significantly impacted the improvement of color indices, such as Browning index, color change, and color index of a* and b*. Moreover, canning treatment reduced the color index of L* in *A. bisporus* mushroom samples. Salting treatment also decreased the shrinkage ratio. Therefore, producers and experts in medicinal-edible mushroom cultivation are recommended to employ these treatments to process and increase the product storage time to maintain the quality characteristics of the mushroom.

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