Shahid Bahonar University of Kerman

Biomechanism and Bioenergy Research

Online ISSN: 2821-1855
Homepage: https://bbr.uk.ac.ir

Iranian Society of Agricultural Machinery Engineering and Mechanization

Design, Manufacturing, and Evaluation a Greenhouse Misting System for Edible Mushroom Production

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ARTICLE INFO

Article type:
Research Article

Article history:
Received 04 May 2024
Received in revised form 20 June 2024
Accepted 08 October 2024
Available Online 31 December 2024

Keywords:
Mushroom, Humidifier, Control, Humidity.

ABSTRACT

Rising global food demand necessitates reducing losses through innovative technologies like greenhouse systems. This research compared and examined the performance of mushroom products in moistened and non-moistened treatments. The research was conducted to investigate the effectiveness of environmental control circuits in two main stages of growing button mushroom. In the first stage, the design of the environmental control circuit and moisture of the mushroom growth chamber were addressed. In the second stage, practical use of a moisture control circuit was applied in the mushroom growth chamber and a complete process of growing button mushroom was carried out. The results showed that mushroom in moistened treatment had significant changes in color and weight characteristics of samples, which had a positive impact. Also, using moisture resulted in less browning index and color changes in all samples. Additionally, weight changes in samples were lower when using a moisture control device. Finally, the results obtained showed that the use of 5% moisture treatment reduced weight changes by 4% and also increased the surface area of the mushroom caps by 13%.

Cite this article: Azadbakht, M., Naseri, R., Mahmoodi, M. J., & Vahedi Torshizi, M (2024). Design, Manufacturing, and Evaluation a Greenhouse Misting System for Edible Mushroom Production. *Biomechanism and Bioenergy Research*, *3*(2), 1-13. https://doi.org/10.22103/bbr.2024.23372.1083

Publisher: Shahid Bahonar University of Kerman
DOI: https://doi.org/10.22103/bbr.2024.23372.1083

INTRODUCTION

The increase in food production and demand in the coming years is a predicted upward trend by humans. However, significant losses and wastage of food occur during transportation, processing, storage, distribution, and post-harvest consumption, (Anand & Barua, 2022). Therefore, the use of innovative technologies to preserve foodstuffs reduces post-harvest losses, mitigating these damages. The absence of innovative technologies, in some cases, leads to food insecurity, necessitating an increase in production (Asige & Omuse, 2022). Considering this issue, greenhouse technology can be utilized, which means that all types of horticultural crops can be cultivated in any region of the world, provided that the greenhouse is properly designed and equipped to control climatic parameters (Ghoulem et al., 2019). However, for profitable and sustainable cultivation of the target product, a much more precise selection of the region based on climatic conditions and the requirements of the selected horticultural product is essential (O'sullivan et al., 2019). On the other hand, sustainable greenhouse production requires integrated management information and strategies, as well as an excellent understanding of the influential environmental climate factors affecting crop cultivation (Mortezapour et al., 2024; Shah & Wu, 2019). In this regard, a proper understanding of changes in the micro-climatic of greenhouses in relation to crop production at various growth stages is of paramount importance (Joshi et al., 2024). On the other hand, greenhouse products are highly demanded globally by both fresh markets and processing industries (Crippa et al., 2021). Additionally, creating a moderate to warm climate in greenhouses, along with improving additional lighting, can significantly impact the growth and performance of a crop in soil, organic beds, soilless mixes, perlite, sand, or hydroponics (Benko et al., 2023). On the one hand, creating an optimal growth environment for the crop in greenhouses is of utmost importance, and this is also essential for improving the performance and quality of the product. However, high humidity inside the greenhouse can easily occur, with plant transpiration being the main source of moisture in greenhouses. Considering this issue, humidity should always be controlled in the greenhouse environment and should not be excessively high. The reason for avoiding high relative humidity inside the greenhouse is that it can lead to plant loss due to fungal diseases, leaf necrosis, and calcium deficiency, resulting in reduced crop yield and quality. On the other hand, the major difference between these concepts in conventional greenhouses and mechanized greenhouses is that air control is partially achieved by window ventilation in conventional greenhouses or completely replaced by mechanical systems in mechanized greenhouses, both of which share two common features: an air processing system and a system for distributing purified air inside the greenhouse (Ghani et al., 2019).

A lack of moisture can lead to significant problems in the growth and development process of flowers, plants, fruits, and vegetables. In nature, plants are naturally provided with the moisture they need (Rademacher, 2015). However, in greenhouses, there is a need to use artificial methods to increase relative humidity. One of the greatest advantages of greenhouses is that plants, vegetables, and fruits can be cultivated and grown in all seasons and climates (Gruda et al., 2019). In this isolated environment, using various greenhouse facilities, all the living conditions of the products (including temperature, humidity, light, air conditioning, soil, water, etc.) are fully provided and controlled (Vatistas et al., 2022). For the growth of any crop, there are specific moisture requirements that entrepreneurs must consider and address for cultivation in greenhouses, depending on particular conditions. Light and carbon dioxide are two important factors in the growth and development of flowers and agricultural products. Plants absorb light and carbon dioxide through the stomata present in their leaves and stems. If the relative humidity is low, these stomata will not open enough for the plant to

absorb sufficient carbon dioxide and light. This moisture deficiency can cause plants to become dry and weak in a short period and may even perish. Adequate moisture is necessary for achieving pollination and fertilization, growth of biological organs, production of flowers and fruits, and overall stages of growth, development, and fertility in agricultural products and ornamental flowers (Malhotra, 2017). Excessive increases in relative humidity can also have various negative effects on the growth, development, and performance of flowers, plants, fruits, and vegetables. If the greenhouse air is excessively humid, it can create many problems compared to moisture deficiency. In fact, reducing relative humidity is usually more challenging than increasing it.

Moisture affects the growth of the product, especially on the surface of the leaves and photosynthesis. Moisture deficiency of about 5 to 10 grams per cubic meter significantly affects the production of carbon dioxide in plants, and reducing moisture also determines the alignment of the leaf surfaces (Umiralievna et al., 2024). The number of stomata in a plant can range from 60 to 1000 per square millimeter, depending on the type of crop, age, leaf position, and growth conditions. In products with a large number of stomata, the stomata are usually small. If there are fewer stomata, the size of the stomata will be larger (Drake et al., 2013). In low humidity conditions, evaporation is high, and the cellular pressure of the products is relatively lower compared to each other. In conditions with low evaporation (low radiation, high humidity), cellular pressure is generally higher and can lead to increased tension. Therefore, the effect of humidity on tension can be better observed under low light conditions (Ferrante & Mariani, 2018).

Moisture is often referred to as a relative number such as Relative Humidity (RH) or Moisture Deficiency (MD), with RH indicating the amount of moisture in the air as a percentage relative to its maximum amount (Ferrante & Mariani, 2018). MD is the difference in moisture content per cubic meter of air that can be added to it at most. Moisture can be continuously discharged and extracted from the greenhouse air. Even in high humidity or low deficiency, due to a very active climate, much of the moisture may be lost, leading to plant dehydration (Babu et al., 2018). Central control devices available in Iran are generally imported, making their prices very high. Additionally, since the display of information and entering commands into them is in English, it is difficult for greenhouse owners to operate them. Sometimes, they need foreign experts for installation, commissioning, and training. Furthermore, because these devices are usually designed and manufactured based on the needs and generally for the common greenhouses of the manufacturer country, there is no possibility of customization and adaptation to the climatic conditions of different regions of our country. Therefore, it is necessary to synchronize greenhouse systems and equipment with central control devices. Given these problems, it is essential to design and develop systems that are modern, efficient, cost-effective, and compatible with the existing technology in the country, to take a step towards progress and self-sufficiency.

MATERIALS AND METHODS

This research was conducted to investigate the effectiveness of the environmental control circuit in two main stages of growing button mushrooms. In the first stage, the design of the environmental control circuit and the moisture of the mushroom growth chamber were addressed. Each component was placed in the electronic circuit to perform a specific task so that its effectiveness on the mushroom yield could be evaluated. In the second stage, practical use of the moisture control circuit was applied in the mushroom growth chamber, and a complete process of growing button mushrooms was carried out.

Preparing the humidity control circuit

An Arduino board with an ATmega328P processor, a DHT11 humidity and temperature sensor, a 12V fan, an adapter, an IRF3205 MOSFET, and a 400 ml/hour ultrasonic cold

steam generation module (atomizer) were used in the design of the humidity control circuit. The arrangement of different parts is shown in Figure 1-2. A 6V adapter was used to use the Arduino board. Base 1, 2 and 4 of humidity and temperature sensor DHT11 were used to measure the humidity and temperature of the chamber. This sensor has reported the measured numbers to the Arduino circuit by its pin 2. Each of the 12 V fan and the ultrasonic cold steam generation module have a separate adapter for power supply. The cold steam production module adapter was 24V. These parts were placed together in such a way that the fan and cold steam production module were activated at the same time. The main board was permanently working on Humidity and temperature data were reported by the DHT11 sensor permanently to the main board.

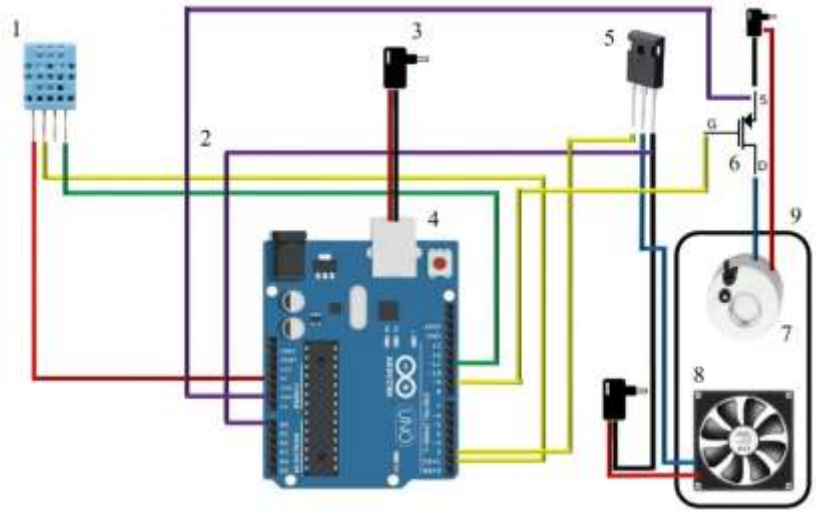

Figure 1. Schematic of the humidity control circuit

(1) DHT11 sensor; (2) Connecting wires; (3) Adapter; (4) Arduino board; (5) Valve; (6) Valve; (7) Ultrasonic cold vapor generation module; (8) Fan; (9) Water reservoir and humidity generation chamber.

Continuing, a 12V fan and an ultrasonic cold vapor generation module were placed together. A specific amount of distilled water was poured into the reservoir of the ultrasonic cold vapor generation module to produce cold water vapor through it. The cold water vapor was directed to the main mushroom cultivation chamber by the fan. Additionally, with the help of the DHT11 sensor, the ability to measure humidity and temperature data was obtained and reported to the main board. The main board and programmed functions were responsible for turning the module and fan on and off. The main board was programmed to maintain humidity at a specific level, so that in case of humidity decrease, the module and fan would start working to increase the humidity. The arrangement of the circuit and the chamber is shown in Figures 2-3.

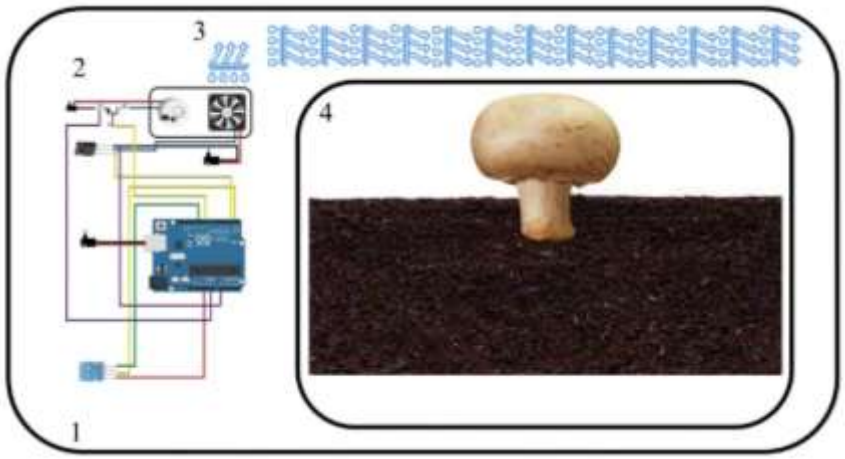

Figure 2. The placement of the humidity control circuit in the button mushroom growth chamber: (1) Main mushroom growth chamber (2) Humidity control circuit (3) Moisture circulation method in the mushroom growth chamber (4) mushroom compost.

Mushroom Growth Space Preparation

The mushroom growth project was conducted in two enclosed chambers. Initially, the chambers were washed and disinfected, and then insulated with adhesive. After insulating the chambers to prevent any contamination, the surfaces and doors of each chamber were entirely covered with plastic. Finally, the interior of the chambers was cleaned with disinfectants. The dimensions of each chamber were chosen to be identical. The mushroom growth chamber along with the humidity control circuit is illustrated in Figure 3.

Figure 3. Mushroom growth chamber with humidity control circuit

Preparation and Maintenance of Compost

The compost used in this study was obtained from a compost production factory in the winter of 2023 AD and then transferred to Gorgan University of Agricultural Sciences and Natural Resources. The process of transferring compost blocks was carried out in a manner to prevent each piece from being placed on top of the other, thus avoiding the compression of seeds inside the blocks and creating anaerobic conditions for microorganisms. The transfer of compost was done in the shortest possible time. Then, the compost blocks were placed in the physical laboratory of the Biosystems Mechanical Engineering Department at a temperature of 20-22 degrees Celsius without wasting time. After transferring the compost to the desired location, the integrity of the packaging of both composts was inspected and confirmed.

Stages of mushroom growth

The stages of button mushroom growth are illustrated in Figure 4 after the introduction of compost into the button mushroom growth chamber. Successful button mushroom growth requires four stages: mycelium growth in compost, mycelium growth in casing soil, aeration, and cropping.

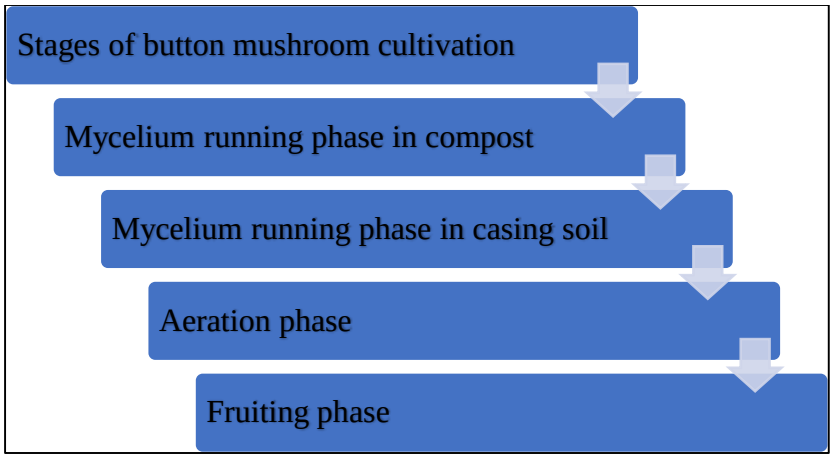

Figure 4. Stages of Button mushroom growth

After arranging the blocks in the prepared and insulated space, the compost residues poured on the floor of the chamber were collected, washed, and completely disinfected. The chamber was washed and disinfected using a solution of one part per thousand of formalin and one part per thousand of Carbendazim fungicide. After placing the compost in the chamber, the compost was heated to match the growth environment for two days. Then, the plastic on the blocks was cut with disinfected scissors. Subsequently, the compost was covered to a depth of about 15 cm. Then, the compost was leveled on the surface and compacted using a disinfected mallet board in a way that the pieces came into contact with each other. Throughout the process, efforts were made to ensure uniformity in all stages. The compacting operation of each of the two chambers was performed separately to prevent drying and compost contamination. Immediately after this stage, the surface of the compost bed was completely covered with paper and plastic. The covered compost surface was regularly irrigated with paper. Irrigation was performed to prevent water accumulation on the surface of the bed. The mycelium propagation stage in the compost was carried out on the 17th day. In this stage, a temperature of 25 to 26 degrees Celsius was provided to facilitate the spread of mycelium. After the complete whitening of the compost, the continued vegetative growth of the mycelium in the casing soil was performed. Casing soil was added to the bed by 2 cm. After placing the soil on the bed surface, the compost and casing soil were mixed together. After the casing soil was fully whitened by the mycelium, aeration was performed to enter the generative phase. Irrigation was carried out simultaneously with aeration. After 7 days following the shock treatment stage, mushroom growth entered the pinning and fruiting stage. The harvest of mushroom in both chambers was performed in three stages or flashes. After the first harvest, irrigation was repeated to create pins for the second flash. Similarly, the third flash was carried out, and the mushroom harvest operation was performed.

Color Analysis

Color analysis utilized values of L, a, and b, independent of the device, providing a broader range compared to RGB and CMYK, employing Image J software for image analysis and color value acquisition. Initially, image preprocessing was conducted to enhance images and remove unnecessary components. The primary goal of image processing was to identify features that could be utilized by users for their purposes. Images were transformed from RGB color space to XYZ and then to L*, a*, and b* through two conversion stages. Utilizing Equation 1, the method employed by San et al., images could be transformed from RGB color space to XYZ color space. Additionally, Figure 5 includes an image captured of the mushroom. The surface area of

the mushroom samples was measured using Image J software, which allows for precise image analysis. The steps involved in the measurement process are as follows: In first step Image for acquisition High-resolution images of the mushroom samples were captured using a calibrated digital camera. Second in image preprocessing, the captured images were preprocessed to enhance clarity and remove any background noise or irrelevant components. This included adjusting brightness and contrast, as well as applying filters to highlight the mushroom surface. For conversion to binary image, the preprocessed images were converted to binary images to distinguish the mushroom from the background. This was achieved using thresholding techniques. Then contour detection the contours of the mushroom were detected using the edge detection feature in Image J. This step helps in defining the boundary of the mushroom. At last surface area calculation, the area within the detected contours was calculated using the software's measurement tool. Image J provides an option to calculate the surface area by counting the number of pixels within the defined boundary and converting it to actual area units using a calibration factor. And for to ensure accuracy, the calculated surface area was validated by comparing it with manually measured areas using traditional methods such as a digital planimeter.

This method ensures accurate and reproducible measurement of the surface area, which is crucial for subsequent analyses and comparisons.

Figure 5. The sample of prepared edible mushroom

Furthermore, equations 2 to 4 can also be utilized to convert XYZ images to L*, a*, and b* in the next stage.

$$\begin{bmatrix}\hat{X}\\ \hat{Y}\\ \hat{Z}\end{bmatrix} = \begin{pmatrix}0412456 & 0.257580 & 0.180423\\ 0212671 & 0.715160 & 0.072169\\ 0.019334 & 0.119194 & 0.950227\end{pmatrix}\begin{bmatrix}\hat{R}\\ \hat{G}\\ \hat{B}\end{bmatrix} \quad (1)$$

$$\hat{L} = \begin{bmatrix}116 \times \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}} - 16\\ 903.3 \times \left(\frac{\hat{Y}}{Y'}\right) ELSE\end{bmatrix} \quad (2)$$

$$\hat{a} = 500 \times \left[\left(\frac{\hat{X}}{X'}\right)^{\frac{1}{3}} - \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}}\right] \quad (3)$$

$$\hat{b} = 200 \times \left[\left(\frac{\hat{Z}}{Z'}\right)^{\frac{1}{3}} - \left(\frac{\hat{Y}}{Y'}\right)^{\frac{1}{3}}\right] \quad (4)$$

In which the values of x', Y', and Z' are the XYZ values for the D65 standard.

$$\begin{bmatrix}\hat{X}\\ \hat{Y}\\ \hat{Z}\end{bmatrix} = \begin{pmatrix}95.047\\ 100\\ 108.883\end{pmatrix} \quad (5)$$

The browning index was also obtained based on the color components and was calculated using criteria 7 and 8 (Moreno et al., 2016):

$$x = \frac{a* + 1.75 \times\times L*}{5.645L* + a* - 3.012b*} \quad (6)$$

$$BI = \frac{(100(x - 0.33))}{0.17} \quad (7)$$

Equations 8 and 9 show the measurement of chroma indices and total color differences to describe color variations during heating of sour orange juice under different process conditions (Jafarzadeh et al., 2022).

The zero indexes of the values read from the sample are not associated with fresh sour orange juice.

$$C = \sqrt{a^{*2} + b^{*2}} \quad (8)$$

$$TCD = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (9)$$

Data Collection and Statistical Analysis

In general, this study was conducted in two completely independent chambers. Chamber number 1 was controlled through a designed electronic circuit. The second chamber was left without a circuit and was placed in its natural state as a control. In each growth flash, with a two-day interval, sampling and photography of the chamber, growth bed, and button mushroom were performed. Samples were weighed using a

0.1 g scale. Then, the mass and color data of the button mushroom were used to plot graphs in Excel software. Additionally, all data were analyzed using factorial design and SAS software.

RESULTS AND DISCUSSION

According to the results obtained from the analysis of variance of treated and untreated moisture (Table 1), the values of all dependent factors L*, a*, b*, Chroma index, brownness index, and overall color change index have been significantly different at a one percent significance level. Significant differences were also observed in weight and cap surface area changes at the one percent level. Considering the significance of the analysis of variance of dependent factors, LSD test was conducted for statistical comparison of these treatments, which is illustrated in Figures 6 to 9.

Table 1. Variance analysis of the effect of humidification treatment on the amount of dependent variables L*, a*, b*, Chroma index, browning index, index of total color changes, changes in weight and surface of Pileus

	L*		a*		b*	
	Average of squares	Significant amount	Average of squares	Significant amount	Average of squares	Significant amount
Moisture treatment	631.14	42.92**	48.28	10.14**	248.64	11.81**
error	12.64		4.76		21.014	
R	0.806		0.457		0.496	
	Chroma index		Browning index		Total color change index	
Moisture treatment	285.24	12.62**	193.14	38.45**	31.50	11.50**
error	22.51		5.02		2.73	
R	0.51		0.762		0.84	
	Weight changes		surface of Pileus			
Moisture treatment	60.07	9.34*	34.60	7.49*		
error	6.42		1.19			
R	0.43		0.707			

** Significance at the 1 percent level*Significance at the 5% level and ns non- significance

Figure 6 shows the comparison of the average color values of L*, a* and b* in different humidity treatments. The results of the comparison of the average for comparing the value of L* show that the treatments that were humidified with a humidifier and were under the humidity treatment had a higher percentage of brightness, and therefore a significant difference was also observed between the condition with a humidifier and a dehumidifier. Mushrooms are very sensitive to changes in their environment and maintaining a constant humidity level is very important for their growth. Humidity affects the ability of fungi to absorb water through their cell walls. If the humidity is too low, the mushrooms may dry out and not grow properly. On the other hand, if the humidity is too high, it can cause the growth of harmful bacteria and fungi that can compete for resources with the fungi and cause disease. For this reason, creating a moisture stability has improved the quality of color and brightness on the surface of the mushroom. Also, the use of a humidifier has increased the brightness of the produced mushroom by 14% compared to the case without the device. The value of a* and b* was also significantly significant for the case where the humidifier were used, where the value of a* was 31% higher than the case without a humidifier, and the value of b* was 14% higher, and both factors had a significant difference. This observation can be due to the increase in brightness of the mushroom surface in the use of the humidity control device and the definition of the lab color system. So that the increase in brightness caused a change in the numerical values of a* and b*.

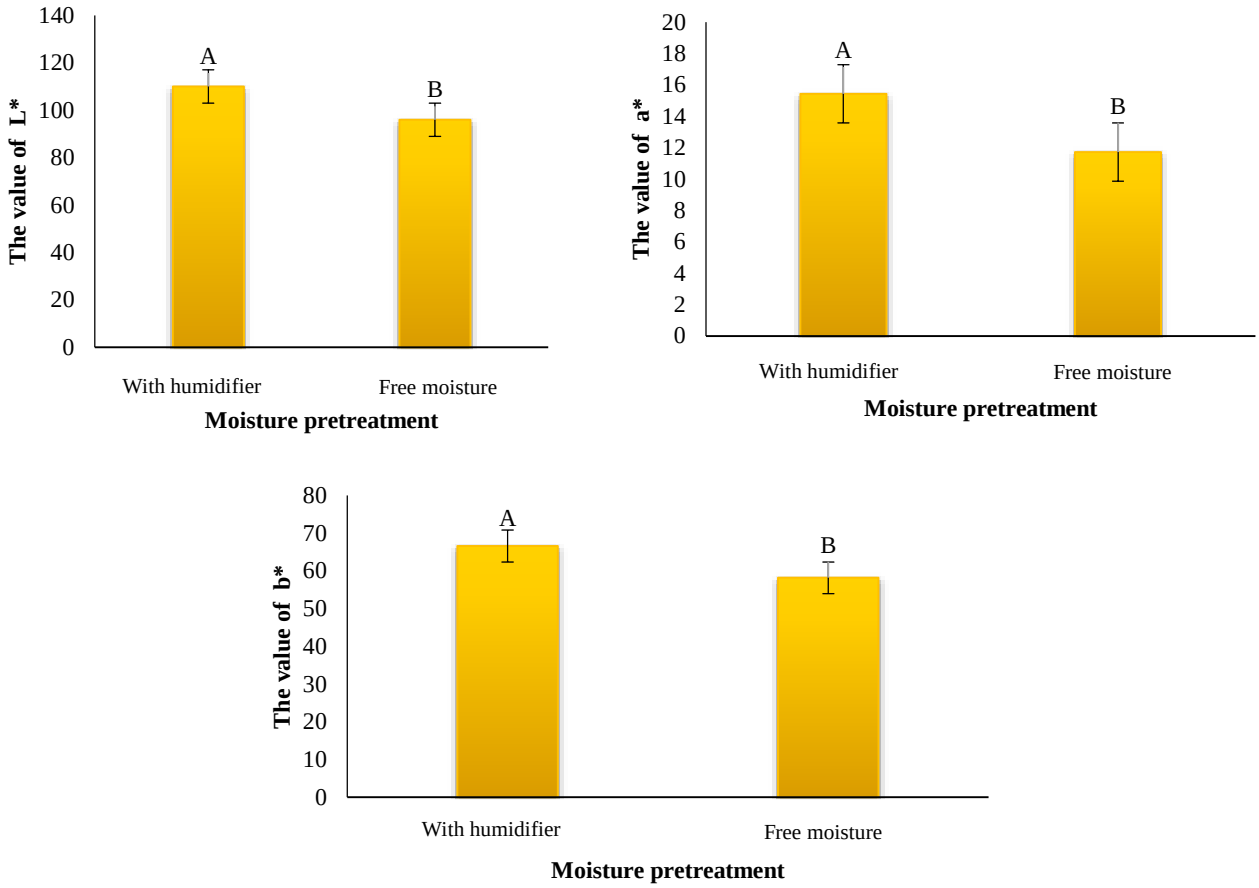

Figure 6. Comparison of average color values L* ،a* و b* under different moisture treatments.

In Figure 7, a comparison of the average color values of the browning index, Chroma index, and total color change index under different moisture treatments is depicted. The Chroma index indicates the purity of a color, and when the Chroma index is high, it means that the amount of white, gray, or black in the sample is higher. Therefore, a higher Chroma index for samples indicates a higher level of whiteness. Chroma can also be considered as the brightness of a color compared to white. According to the results obtained, samples subjected to moisture treatment contain 15% more moisture, and a statistically significant difference has been observed. For the total color change index, the amount of color change for samples without moisture treatment has been higher, and a significant difference has been noted. Similar results have been obtained for the browning index factor as well. This result can be due to the very high sensitivity of the mushroom surface to the lack of moisture in its cultivation environment. The difference in these two factors between the moisture-treated and untreated states is approximately 50%.

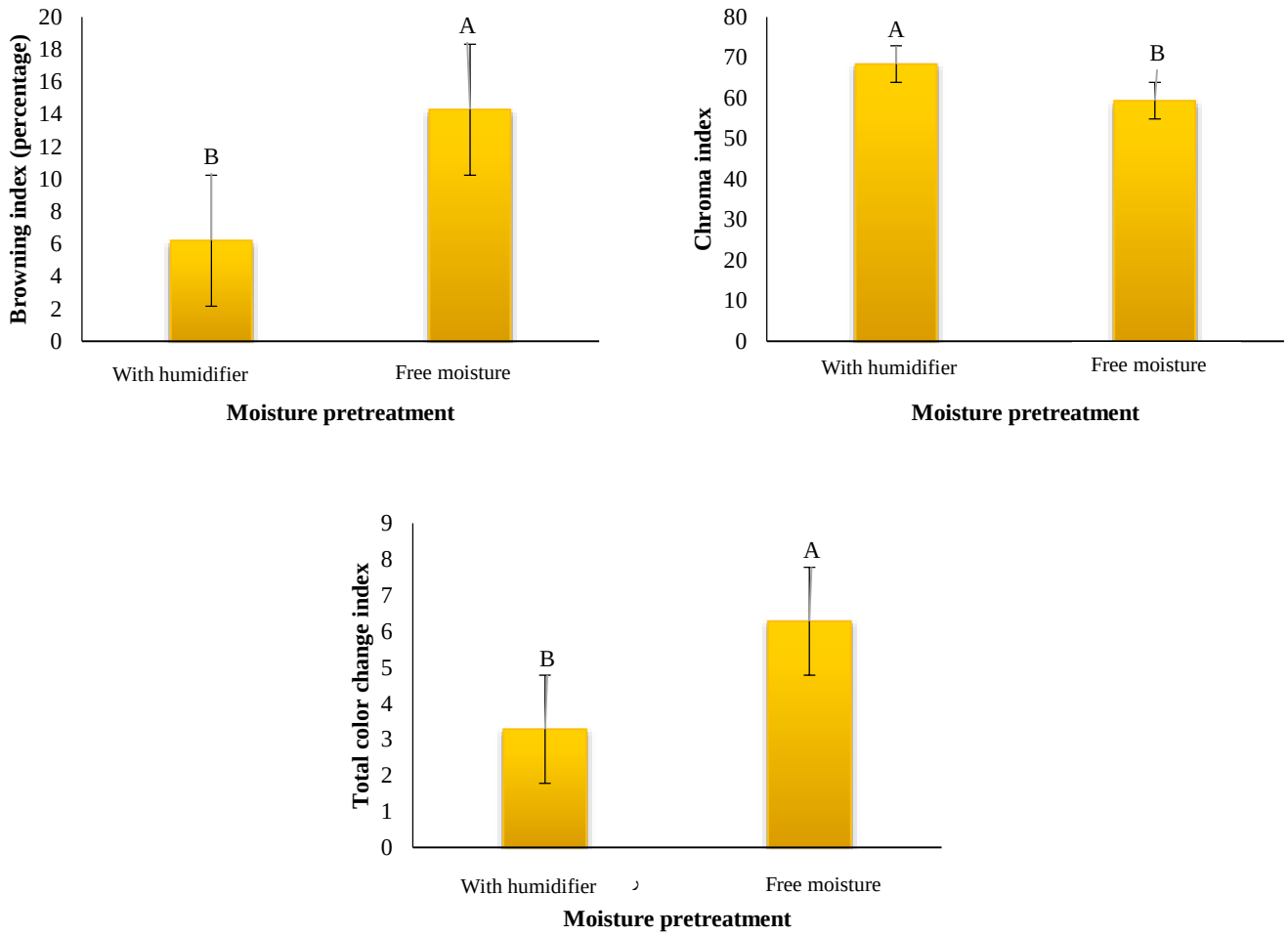

Figure 7. Compares the average color values of the browning index, Chroma index, and total color change index under different moisture treatments.

Figure 8 illustrates the comparison of average total weight changes under different moisture treatments. Examining the comparison of the average total weight change factor post-harvest reveals that samples subjected to moisture treatment experienced less weight variation over a 5-day period, with the percentage of weight changes in samples without moisture treatment being higher. This observation is justified by the fact that the lack of moisture resulting from not using the device has caused the quality of the button mushroom to decrease and as a result increase its weight changes. Additionally, overall, the weight of mushroom treated with moisture was higher on average, indicating their higher moisture content. According to the results obtained, when moisture was not used, the weight of the samples decreased by 10.42%, while for moisture-grown mushroom, the decrease was 6.28%.

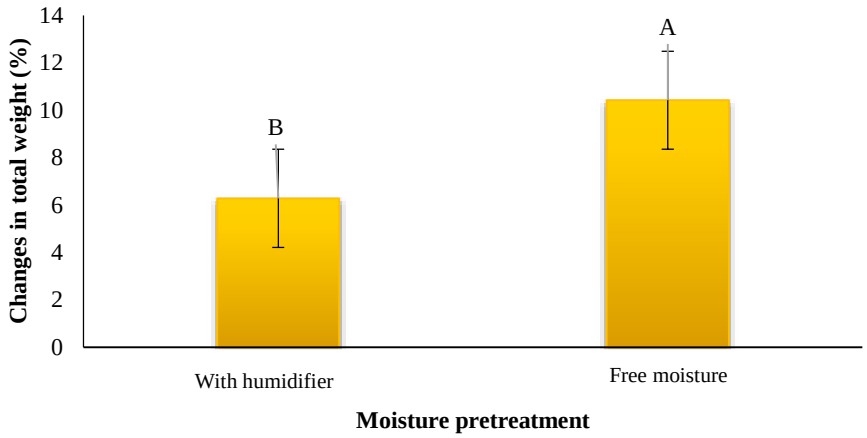

Figure 8. A comparison of average total weight changes under different moisture treatments.

Figure 9 illustrates the comparison of the average surface area of pileus under different moisture treatments. Comparing the dimensions of the cap surface, which is highly important for consumer preference, it's observed that the moisture-treated samples have a greater surface area of pileus. The decrease in humidity caused by not using the device has caused a decrease in the humidity and quality of the mushroom, and as a result, surface shrinkage and a decrease in the surface of the button mushroom. According to the average comparison, this difference is approximately 3 cm^2 larger than the surface area of mushroom without moisture treatment, and statistically significant differences have also been observed between them. The highest amount of pileus surface area was 27.51%, and the lowest amount was 24.37%. Moisture usage increased the pileus surface area by 3%.

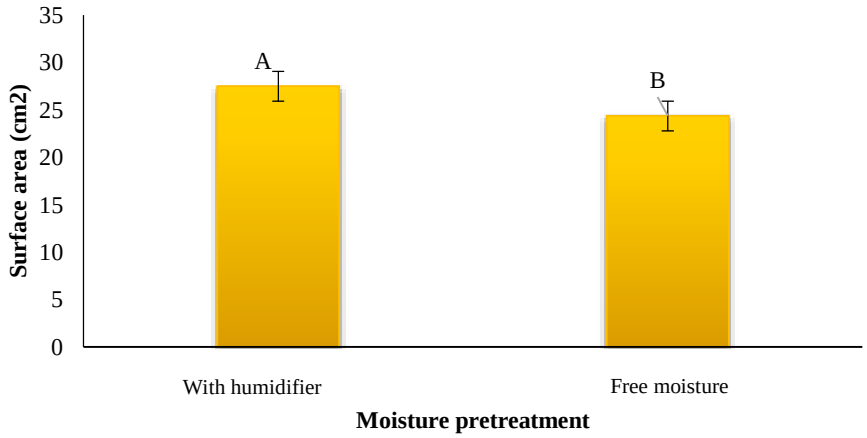

Figure 9. Comparison of the average level of button mushroom under different humidity treatments.

CONCLUSIONS

Based on the obtained results, it can be stated that the use of a humidity control device has led to significant changes in the color and weight characteristics of the mushroom samples, with a positive effect overall. Furthermore, the use of humidity has resulted in less variation in the browning index and overall color changes of the samples, while the weight variations of the samples were lower when using the humidity control device.

Acknowledgements

We are grateful to the Gorgan University of Agricultural Sciences and Natural Resources for their support.

Data Availability Statement

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

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