Optimization of chanterelle mushroom drying kinetics under heat pump dryer using Taguchi design method

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Abstract: The optimum drying conditions with regard to minimum color changes, high rehydration ratio and drying rate for chanterelle mushrooms is inadequately known. To address this problem, drying kinetics for chanterelle mushroom samples with sizes of 20 mm×20 mm×20 mm cube, 20 mm×20 mm×30 mm cuboid, and Ø40 mm×20 mm cylindrical shape were experimented. Drying air temperatures of 40°C, 48°C, and 56°C at superfluous humidity and velocity of 2.2 m/s were used. Initial color pixels for each sample were determined using Note 8 Pro Xiaomi smartphone camera and image processing tool in Matlab R2019a. Triplicate experimentation was done based on L_9 Taguchi orthogonal arrays with drying rate, specific moisture extraction rate, color change, and rehydration ratio being the response parameters. The drying rate increased from 1.1174 g/g·min to 1.3478 g/g.min as the temperature rose from 40°C to 56°C. The mushroom cube had the highest drying rate of 1.2860 g/g·min while the cylindrical shape had the lowest rate of 1.1764 g/g·min. Similarly, SMER increased from 0.006 326to 0.013 27 g/kWh with the temperature rise. Contrary, SMER decreased from 0.006 92 to 0.013 63 g/kWh in cylinder to cube respectively. Color change was highest at 40°C (13.49) and lowest at 56°C (11.94). The mushroom cube had the lowest color change of 9.28 on average when compared to other shapes. Rehydration ratio was highest at 56°C (3.824) as compared to 48°C and 40°C. Additionally, the mushroom cube had the highest rehydration ratio of 4.55 on average as compared to other shapes. Temperature variation significantly influenced the drying rate and SMER. However, temperature variation had insignificant differences in color change and rehydration ratio. Mushroom shape variation had a significant difference in all the response variables tested. Conclusively, mushroom cubes at the drying temperature of 56°C gave optimized drying conditions for chanterelle mushrooms with minimal quality deviations. Thus, chanterelle mushrooms can be sliced into cubes to allow quick drying rate, better SMER, rehydration ratio, and have minimal color change.

Keywords: optimization, chanterelle mushrooms, drying kinetics, heat pump dryer, Taguchi design
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1 Introduction

Worldwide mushroom consumption is rapidly increasing. This is prompted by their use as food and medicines. Their intake can prevent and minimize long-term ailments affecting humanity like cancer, cardiac diseases, diabetes, and neuron-related diseases[1]. Dried mushrooms are used as constituents in casseroles, soups, salads, wadding, meat, and rice dishes[2]. Short shelf-life and high product variability are among the commonest challenges in the mushroom industry[3]. Readily harvested mushroom contains about 90% water content and drying them at temperatures of 55°C-70°C to the final moisture content of about 10% reduces putrefaction[4,5]. High initial moisture content makes mushrooms bulky and easily decayable henceforth affecting quality[2,6,7]. For instance, mushrooms turn brown and lose quality a few days after harvesting because of high harvesting moisture content[8]. For instance, the stay period of harvested mushrooms is less than 5 d depending on the variety and storage method employed[7]. Mushroom qualities comprise color, size, firmness, maturity level, lucidity, aroma, and nutritional content[9]. Most of these qualities are influenced by post-harvest treatments especially drying. Drying is the most frequently applied post-harvest preservation method due to its ability to maintain the nutritive qualities of food[10]. For example, surface drying of mushrooms can competently constrain browning by reducing enzymatic activities[8].

Chanterelle mushrooms (*Cantharellus cibarius*) are comestible mushrooms with apricot-like aromas and nice textures harvested mostly between winter to early spring seasons[11]. They are used in different forms such as fresh, dried, frozen, and pickled products[12]. Mature chanterelle mushrooms have stipe diameters ranging from 3.5-5.0 cm and heights up to 25.0 cm long. These dimensions make heat and mass transfer processes to be slow thus causing spoilage and transportation difficulties over time. These challenges need to be controlled to avoid food loss that leads to food insecurity. Conventional hot-air drying is among the most important preservation methods for chanterelle mushrooms due to its simplicity, cost-effectiveness, and competence in extending the shelf-life of mushrooms[13]. This is prompted by the fact that drying

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reduces the water activity (a_w) of products till they are physical-chemically stable[14]. Nevertheless, drying mushrooms for a long time causes surface overheating, blackening, cellular rupture, flavor loss, and unbalanced rehydration[9]. Therefore, there is a need for an optimized drying process to minimize these undesirables. Chanterelle mushrooms are mostly dried by slicing them longitudinally, chopping, or wholly. This calls for the necessity to determine air temperature and mushroom shape with optimized drying kinetics to minimize operational costs. Also, little knowledge is available regarding drying mushroom cubes, cuboids, and cylinders which are deemed to dry faster than whole ones. Heat pump drying serves as one of the appropriate technologies for mushroom drying. The dryer can recover energy from recycled moist air hence minimizing energy consumption. Furthermore, the method enables easy control of drying parameters resulting in quality products and lowered unit energy consumption[15].

Taguchi's robust design method is one of the best-optimizing tools since it provides a simple, effective, and systematic method for optimizing, quality[16]. The method uses orthogonal arrays (OA) to conduct optimization experiments thus reducing time and number of trials for given objectives. This is done by using signal-to-noise ratio (S/N) that optimizes quality based on the reduction of variations during processing. Orthogonal array accounts for the number of setups done[17]. The size and shape of the mushroom during drying are deemed to affect the drying rate which has effects on color, specific moisture extraction rate (SMER), and rehydration ratio. Nonetheless, inadequate literature on the optimal combination of these drying parameters in drying chanterelle mushrooms under a heat pump exists. Therefore, the current research sought to determine the drying kinetics of chanterelle mushrooms under a laboratory heat pump dryer with the objective of maximizing the drying rate, specific moisture extraction rate, rehydration ratio, and minimizing color change during the drying process of chanterelle mushrooms.

2 Materials and methods

2.1 Sample preparation and experimentation

Clean fresh chanterelle mushrooms of commercial rating were bought from Sugou supermarket, Pukou district, Nanjing, China, and refrigerated at 4°C for 24 h prior to experimentation. They were cut into 20 mm×20 mm×20 mm cube, 20 mm×20 mm×30 mm cuboid, and 20 mm×Ø40 mm cylindrical shapes. 500 g mushrooms were used in each experiment. Initial images for color analysis of each sample were determined using a smartphone camera (Redmi Note 8 Pro Xiaomi Technology Company Ltd., Beijing, China) and image processing tool in MATLAB R2019a. Chanterelle mushrooms were dried using a laboratory heat pump at the Department of Agricultural Mechanization, Pukou campus, Nanjing Agricultural University, China. The heat pump was run for 30 min to stabilize the drying temperature prior to respective experimentation. Drying air temperatures varied from 40°C, 48°C, and 56°C while mushroom shapes used were cubes, cuboids, and cylindrical shapes. Temperature and Mushroom shape variations were intuitively selected due to inadequate information on their influence on the quality of chanterelle mushrooms. Relative humidity and drying air velocity were treated superfluously. L_9Taguchi experimental design technique was used for the optimization experiments.

2.2 Drying rate determination

Moisture content for fresh and dried samples was determined using the oven drying method according to the prescriptions found in American Society of Agricultural Engineers (ASAE) standards S352.2. Sample weights were taken and recorded at intervals of 30 minutes till insignificant mass change was noted using the precision weighing balance (Jsc-600 electronic balance, Kaifeng Group Co. Ltd). Equation (1) was used for drying rate determination. Variation of drying rate (g/g·min) with temperature and mushroom shape variation with time were analyzed.

$$\mathrm{dr} = \left[\frac{m_i - m_{i+1}}{\Delta t}\right] \tag{1}$$

where, dr, m_i, m_{i+1}, and Δt are drying rate, previous moisture content in dry basis form (db), subsequent moisture content (db), and change in time with $i = 0, 1, 2, 3...$, respectively.

2.3 Specific moisture extraction rate determination

SMER refers to the mass of moisture removed during drying per unit of electrical energy supplied[18]. High SMER indicates high thermal efficiency during drying[15]. Therefore, the higher the SMER the better and more efficient the drying process. Accordingly, the Taguchi technique for the higher the better objective was chosen to give optimal parameter combination for maximized SMER (Table 1).

Table 1 Signal-to-noise ratio (S/N) and the response to be optimized

Name	Mathematical formula	Application	Applicable Response
Larger the better	$S/N = -10\log_{10}\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$	When the aim is to maximize the response parameter.	Drying rate SMER Rehydration ratio
Nominal the best	$S/N = 10\log_{10}\frac{\bar{y}}{s_y^2}$	When the intention is to target a pre-determined S/N ratio	--
Smaller the better	$S/N = -10\log_{10}\frac{1}{n}\left(\sum y^2\right)$	It is applied when minimizing the response parameter	Color change

Note: n is the total samples; y is the individual sample observations. SMER: Specific moisture extraction rate.

This was done by recording meter readings before and after drying each of the three shapes of chanterelle mushrooms under experimentation. The difference between the meter readings before and after the drying process gave the total energy Q in kWh used for the drying process. Consequently, the total energy was used aptly for the calculation of SMER using Equation (2).

$$\mathrm{SMER} = \frac{M_o - M_e}{Q} \tag{2}$$

where, SMER refers to the specific moisture extraction rate; M_o is initial moisture content; M_e is equilibrium moisture content; Q is the total energy used for the total moisture extracted from the respective mushroom shape, kWh.

2.4 Color change analysis for mushrooms drying

Color is among the most important qualities desired by consumers of many food products, especially mushrooms[19]. During color measurements, images of fresh 20 mm×20 mm×20 mm fresh mushrooms and the dried samples were captured using a smartphone camera (Redmi Note 8 Pro Xiaomi Technology Company Ltd, Beijing, China) at intervals of 30 min. The smartphone had a rear camera equipped with 64 Megapixels (MP)+8MP+2MP+2MP and a resolution of 2340×1080 pixels. Chanterelle mushroom samples were put in a black plate as a background for better contrast since mushrooms were presumed white-like. The distance between the black plate and the smartphone camera was set at 200 mm vertically. Captured images were transferred to the image processing tool in MATLAB R2019a version for determining mean Red, Green, and Blue (RGB) values.

Mean RGB was then converted to XYZ tristimulus values and finally to Hunter Lab values using relevant equations in MATLAB 2019a software. Equation (3) was used to determine mushroom color change (ΔE) at intervals of 30 min for the respective trial.

$$\Delta E = \sqrt{(L-L_o)^2+(a-a_o)^2+(b-b_o)^2} \quad (3)$$

With the Hunter L being the lightness or darkness (black, L=0; white, L=100), +a is redness, −a is greenness, +b is yellowness, and −b is blueness[19,20]. L_o, a_o, and b_o were the subsequent Hunter Lab values. Chroma (C^*) and hue (H^o) were calculated, using Equations (4) and (5). C^* represents color saturation. Hue (H^o) values range from 0° (pure red), 90° (pure yellow), 180° (pure green) to 270° (pure blue)[10].

$$C* = \sqrt{a_o^2+b_o^2} \quad (4)$$

$$H^o = \tan^{-}\left(\frac{b_o}{a_o}\right) \quad (5)$$

The smaller the better option was used for color change optimization since a small color change is desired during the drying of chanterelle mushrooms and most other vegetables (Table 1).

2.5 Determination of Rehydration ratio

The rehydration ability of dried agricultural products demonstrates the level of damage caused by physical and chemical processes occurring during drying[13]. A mass of 10 g of dried chanterelle mushrooms was dipped in a flask with tap water for 30 min. The rehydrated samples were removed and carefully dried off using tissue paper and reweighed. Equation (6) was used to determine the rehydration ratio of dried samples at varying temperatures and shapes.

$$R_h = \frac{W_r}{W_d} \quad (6)$$

where, R_h is the rehydration ratio; W_r is the weight of rehydrated mushrooms; W_d is the weight of dehydrated mushrooms[21,22].

2.6 Taguchi optimization of drying process

Taguchi technique is a powerful tool for the design of high-quality systems and processes like drying due to its high efficiency, simplicity, quality, and cheapness[16]. The technique advances the quality of products by curtailing the outcomes of variational causes without disregarding the causes. This is attained through the use of signal-to-noise ratio (S/N) which measures quality and orthogonal arrays used to analyze numerous design parameters concurrently[23]. Subsequently, L_9 orthogonal array was used for experimentation. The experiments were done in triplicate and the mean values were recorded for analyzing the drying rate, SMER, Rehydration ratio, and color change of mushroom samples. The inbuilt Taguchi analysis software in Minitab-19 was used to find the optimum combination of air temperature and mushroom shape using relevant relations as indicated in the applicable responses (Table 1). The Minitab-19 software has an inbuilt setting for the Taguchi method from which the desired response is selected.

2.7 Statistical Analysis

The chanterelle mushrooms drying under a heat pump dryer were experimented with in triplicate. The influence of temperature and mushroom shape on drying rate, SMER, rehydration ratio, and color change were analyzed and presented in tabular and graphical forms. Graphs were drawn using OriginPro 2021 version. In determining if there was a significant difference in means, the least significant difference (LSD) was performed at a 5% significance level for the effects of chosen variables on the selected response factors. Statistical analyses were performed using Minitab-19 (Minitab Inc. USA for Windows®) and GenStat software.

3 Results and discussion

3.1 Chanterelle mushrooms drying rate characteristics

Figure 1 shows the drying curves for temperature and chanterelle mushroom shape variations. There was a falling rate period in the drying of chanterelle mushrooms under temperature and shape variations as time lapsed. Fresh chanterelle mushrooms with an average moisture content of 91.7% (wb) averagely dried to 9.5% (wb). From Figures 1a-1c, an increase in drying air temperature from 40°C to 56°C increased the drying rate for chanterelle mushrooms correspondingly. This implied that rise in air temperature increased the moisture removal rate as compared to the lower temperature which indicated a lower drying rate hence agreeing with documented literature[2,14,24,25]. This observation was attributed to the high-temperature gradient in the air-product interface causing a high drying rate with temperature rise. The high-temperature gradient was a major driving force for heat and mass transfer for the mushrooms. The other cause of the high drying rate was the high moisture gradient in drying mushrooms, especially at the initial stages of drying. This led to increased heat and mass transfer causing a fast-initial drying rate as compared to when moisture equilibrium was approached. This observation was evidenced after 330, 270, and 570 min which had high drying rates as temperature dropped from 56°C to 40°C, respectively.

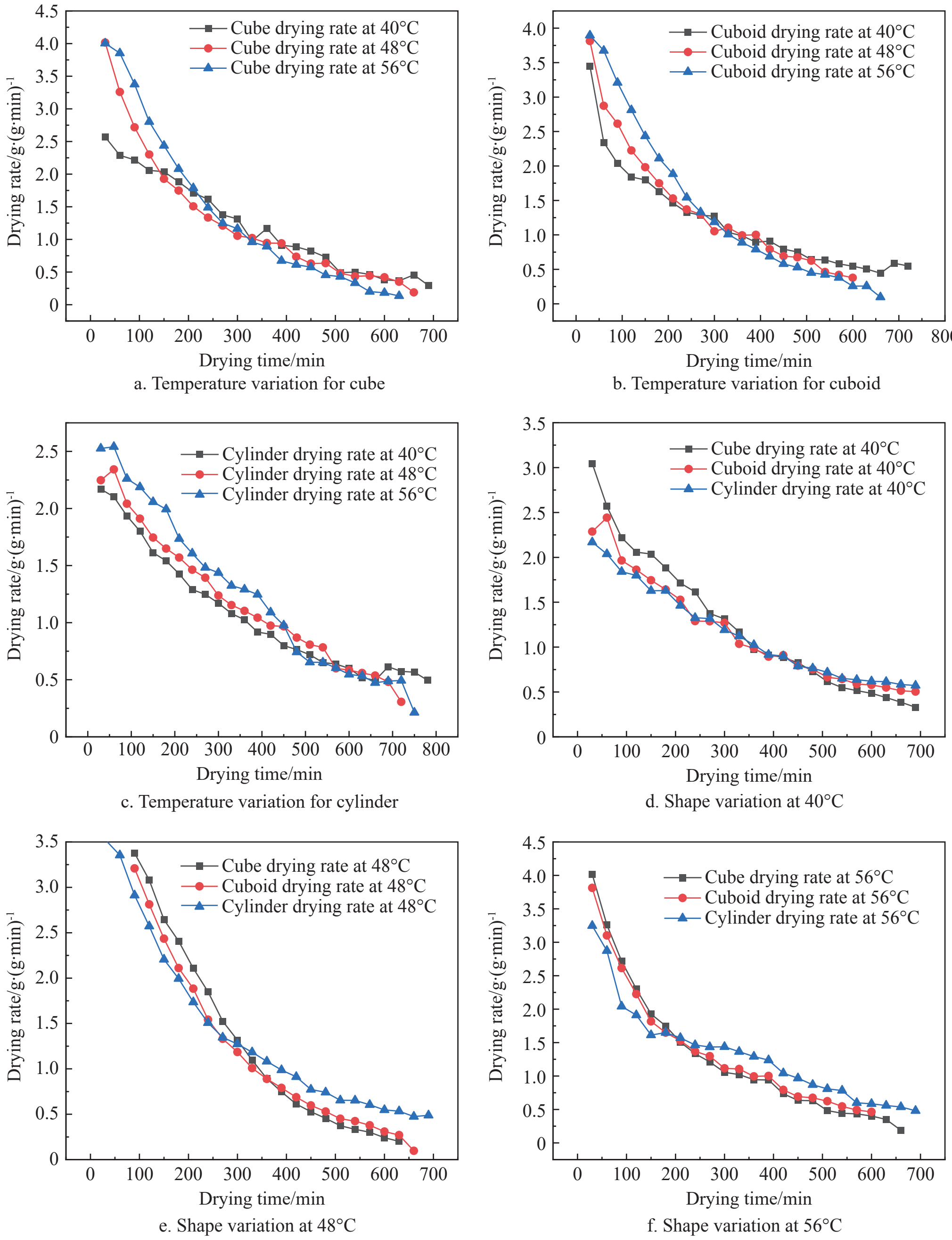
However, after intersection time (330, 270, 570 min), the mushrooms drying at lower temperatures had not approached equilibrium moisture content (EMC) when compared to those drying at higher temperatures. This caused a slightly high drying rate after the intersection time because of the high moisture gradient at 40°C and 48°C. Thus, high temperature causes high drying rate, especially at the initial drying stage when the moisture gradient is high. Similar observations have been made in drying potato slices in forced convection dryer[26].

However, as drying progresses, the influence of temperature gradient on the drying rate diminishes leaving the diffusion gradient to monopolize the process hence the observation after the intersection time. Accordingly, the phenomenon central to moisture migration in chanterelle mushrooms was dominated by moisture diffusion through intermolecular spaces into the drying air due to diffusion gradient. This observation corresponded to those reported in literature [27, 28].

In Figures 1d-1f, the cube had the highest drying rate followed by the cuboid and cylindrical shape respectively. This showed that the mushroom cube had the highest drying surface area to volume ratio followed by cuboid and cylinder shapes. Even though the three shapes had the same volume, the cube had more exposed surface area to drying air thus raising the evaporation as compared to the cuboidal and cylindrical shapes. The resultant effect of high surface area to volume ratio is the increased heat and mass transfer rate as observed in the mushroom cube. The observation agrees with literature [26, 29]. Intersection time for chanterelle mushroom shape variations were 390, 300, and 210 min respectively. After intersection time, mushroom cube had low drying rate followed by the cuboid and cylinder due its high initial drying rate.

3.2 Specific moisture extraction rate in chanterelle mushrooms

Figure 2 shows the average SMER for chanterelle mushroom at temperatures of 40°C to 56°C and cube, cuboid, and cylindrical shape. SMER increased with the rise in temperature from 40°C to 56°C respectively. This implied that temperature rise caused an increase in heat and moisture transfer within the intermolecular spaces in chanterelle mushrooms. In terms of mushroom shape variations, mushroom cube had the highest SMER followed by cuboid and cylinder respectively. This implied that the cube had large surface area for heat and mass transfer hence high amount of moisture was extracted per unit kWh (SMER). Thus, drying air temperature and mushroom shape play a significant role in SMER for chanterelle mushrooms.



a. Temperature variation for cube
b. Temperature variation for cuboid
c. Temperature variation for cylinder
d. Shape variation at 40°C
e. Shape variation at 48°C
f. Shape variation at 56°C

Figure 1 Chanterelle mushrooms' drying curves at varying temperatures and shape

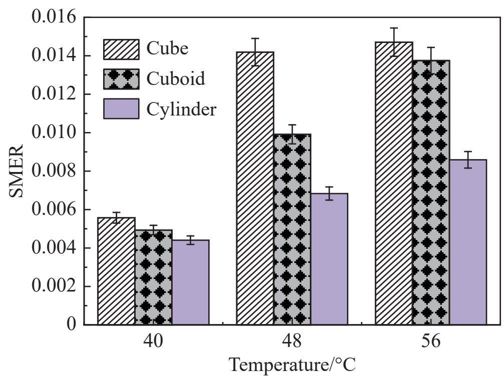


Figure 2 Temperature and shape variation effect on SMER

Research done on other agricultural products like tomatoes shows that SMER is directly proportional to surface area to volume ratio[30]. Materials with a higher surface area like the cubicle mushroom shape had higher SMER (Figure 2).

3.3 Color changes in drying chanterelle mushrooms

The maximum value of brightness (L) is the yardstick for the color quality of dried mushrooms and other agricultural products[13]. Color changes have significant impacts on customer acceptance of mushrooms[31]. The color changes for chanterelle mushroom samples vary from cube, cuboid, and cylinder with temperature varying from 40°C-56°C (Table 2). It was observed that luminosity (L) ranged from 65.4 to 76.6 and increased with the rise in temperature from 40°C-56°C. This indicated that faster drying caused by higher temperature reduced enzymatic and other biochemical reactions that caused browning in dried chanterelle mushrooms. There was also more reddening (−a) in most samples with the highest reddening observed in the cylinder at 40°C indicating the negative effects of a lower drying rate on chanterelle mushrooms.

Table 2 Color values of heat pump dried mushrooms under the selected parameters

Parameters		color properties of dried chanterelle mushrooms					
Mushroom shape	Temperature	L^*	a^*	b^*	ΔE	Chroma (C^*)	Hue (H^o)
	40°C	72.2±7.2	−1.5±0.8	13.4±4.8	15.0±8.4	14.9±6.7	63.6±26.2
Cube	48°C	74.5±4.2	−0.6±1.0	18.5±5.6	17.8±6.4	18.6±5.6	39.4±22.3
	56°C	65.4±7.1	17.3±9.3	12.1±5.4	4.1±6.5	17.7±5.5	58.0±17.6
	40°C	75.6±4.4	−1.6±0.7	14.6±5.6	12.7±6.5	14.8±5.6	71.9±26.6
Cuboid	48°C	71.0±4.1	−0.9±1.1	15.1±4.4	13.4±5.8	15.3±4.4	50.7±26.8
	56°C	74.2±3.2	−1.5±0.6	18.3±6.8	14.9±7.2	18.4±6.8	69.5±25.1
	40°C	72.5±4.0	−3.1±1.5	13.6±4.6	9.7±5.7	14.0±4.8	61.3±29.5
Cylinder	48°C	73.4±2.7	−1.2±1.0	13.5±3.3	9.2±3.3	13.7±3.3	47.6±25.9
	56°C	76.6±2.6	−2.4±1.2	13.9±4.9	9.2±4.1	14.2±5.1	67.6±21.6

The browning index (+b) was less in a cube drying at 56°C as compared to other chanterelle mushroom shapes. The lowest color change (ΔE) was profound in cube drying at 56°C. This was attributed to the high drying rate in the cube at 56°C which gave less time for biochemical and enzymatic actions presumed to cause more color change at high water activity (a_w). Hue (H^o) values were highest at lower temperatures as compared to higher temperatures. This implied that there was more yellowing at lower temperatures due to the long exposure time to enzymes and other biochemical reactions due to the low drying rate. The color saturation (C^*) was lesser at lower temperature as compared to high temperature. (H^o) values were higher at 40°C in cube and cuboid indicating more yellowing at lower temperatures. In terms of mushroom shape variations, mushroom cube had average lower hue values than cuboid and cylinder samples.

Therefore, there was lower yellowing in cube shape when contrasted to other chanterelle mushroom shapes. Color changes during hot-air drying were presumably caused by enzymatic and non-enzymatic browning reactions as reported in literature[13]. Over-subjecting mushrooms to a lower drying rate gives more time to enzymatic and non-enzymatic reactions hence more browning of chanterelle mushrooms. The results were in agreement with those made by other researchers in drying various crops[8,31-33].

3.4 Effects of rehydration ratio in drying chanterelle mushrooms

The rehydration ratio ranks among the quality characteristics of dried agricultural produce, especially mushrooms. The rehydration ratio of dried agro-products is used as a guide for structural quality. This majorly relies on the drying conditions employed[31]. The results revealed that chanterelle mushrooms significantly fluctuated after drying when compared to fresh mushrooms. This was ascribed to a loss in moisture that caused reduced and shrunken mushroom samples after drying.

Figure 3 shows the effects of both mushroom shape and temperature variations on the rehydration ratio of chanterelle mushrooms. Mushroom cube had the highest rehydration ratio followed by cuboid and cylindrical shapes at 56°C, respectively. The same trend was true for 48°C and 40°C.

It was proposed that under similar drying conditions, more moisture was removed from mushroom cubes because of the large surface area for drying as compared to the cuboid and cylinder. This created more intermolecular spaces in the mushroom cube that led to higher water intake when compared to other mushroom shapes. Therefore, drying a mushroom cube at 56°C gave the maximum rehydration ratio for chanterelle mushrooms as similarly observed by other researchers[7].

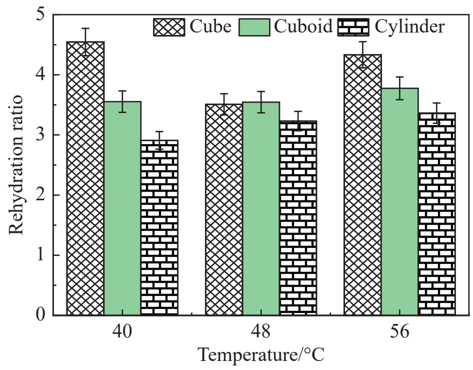


Figure 3 Influence of shape and temperature on dried mushroom rehydration ratio

Table 3 lists the LSD for the effects of temperature and mushroom shape variations on the four response parameters. There was a significant difference at α=5% significant level using LSD in drying air temperature and chanterelle mushrooms' shape variations on drying rate and specific moisture extraction rate.

Table 3 Mean response for the influence of selected parameters for mushroom drying

Parameters	Level	Response			
		Drying rate/ g·(g·min)$^{-1}$	SMER/ g·kWh^{-1}	Color change	Rehydration Ratio
	40°C	1.1174^a	0.006 326^a	13.49^a	3.428^a
Temperature	48°C	1.2548^b	0.008 67^a	12.82^a	3.741^a
	56°C	1.3476^b	0.013 27^b	11.94^a	3.824^a
	LSD	0.1116	0.003 586	4.245	0.545
	Cube	1.2860^a	0.013 63^a	9.28^b	4.55^a
Mushroom shape	Cuboid	1.2575^a	0.007 71^b	13.26^a	3.656^b
	Cylindrical	1.1764^a	0.006 92^b	15.71^a	2.786^c
	LSD	0.1116	0.003 586	4.245	0.545

Note: Superscript lowercase letters mean that do not share a letter and are significantly different at α=5% significant level using LSD.

However, temperature variation had insignificant differences in rehydration ratio and color change for the current research. Varying chanterelle mushroom shapes significantly influenced all the response parameters tested.

3.5 Taguchi optimization of chanterelle mushrooms drying characteristics

Taguchi technique enables the analysis and application of many process parameters using a few experiments[16,34]. Tables 4-7 list Signal to Noise ratios for the effects of parameters on the response factors as generated using Minitab-19 (Minitab Inc. USA for Windows®). With regard to drying rate (Table 4), whose design objective was to have a high drying rate, a combination of mushroom cubes dried at 56°C gave the desired drying rate for Chanterelle Mushrooms.

Temperature variations had more influence on chanterelle mushroom drying rate as compared to mushroom shape. Drying mushroom cubes at the temperature of 56°C gave the highest drying rate.

Table 4 Response table for Signal to Noise ratios for drying rate

Level	Temperature	Mushroom shape
1	0.9044	2.0827
2	1.8491	1.9162
3	2.5465	1.3010
Delta	1.6421	0.7817
Rank	1	2

Table 5 Response table for Signal to Noise ratios SMER

Level	Temperature	Mushroom shape
1	−45.91	−38.61
2	−43.94	−45.26
3	−38.73	−44.71
Delta	7.18	6.65
Rank	1	2

Table 6 Response table for Signal to Noise ratios for color change

Level	Temperature	Mushroom shape
1	−21.52	−24.22
2	−22.74	−22.66
3	−22.36	−19.73
Delta	1.23	4.49
Rank	2	1

Table 7 Response table for Signal to Noise ratios for rehydration ratio

Level	Temperature	Mushroom shape
1	11.261	12.882
2	10.267	11.102
3	11.196	8.741
Delta	0.994	4.141
Rank	2	1

Drying a cubical mushroom shape at 56°C gave the optimal conditions for maximum SMER during the drying process (Table 5).

Temperature variations had more influence on the SMER as compared to chanterelle mushroom shapes. For a minimum color change, a combination of cubes dried at 48°C gave the optimal condition (Table 6). However, variation in mushroom shape had more influence on color as contrasted to temperature variations. Drying cubes of mushrooms at 48°C further gave low discoloration of Chanterelle Mushrooms. However, temperatures of 48°C and 56°C had insignificant differences in varying color change. Consequently, drying Chanterelle Mushrooms at 56°C did not cause large deviations in the final results due to the small SN differences (0.38).

Chanterelle mushroom cube dried at 56°C resulted in the maximum rehydration ratio (Table 7). The mushroom shape had more influence on the rehydration ratio in comparison to varying drying air temperature. Accordingly, drying chanterelle mushroom cubes at 56°C had minimal differences in rehydration ratio.

Therefore, chanterelle mushroom cubes dried at 56°C gave optimal heat pump drying conditions for the selected response parameters.

4 Conclusions

Drying is among the vital unit processing operations for the production of quality chanterelle mushrooms. Drying air temperature and mushroom shape influenced the drying rate, SMER, color change, and rehydration ratio of chanterelle mushrooms. The drying rate, SMER, and rehydration ratio increased with the rise in drying air temperature from 40°C-56°C. However, the color change was reduced in chanterelle mushrooms drying with the rise in temperature from 40°C-56°C. Consequently, the lower drying rate subjected chanterelle mushrooms to browning by allowing more time for biochemical and enzymatic actions. With regard to mushroom shape variations, drying rate, SMER, and rehydration ratio declined from cube, cuboid, and cylinder respectively. This implied that surface area to volume ratio which is influenced by shape affected mushroom drying rate hence the observations in SMER, color change, and rehydration ratio. Temperature variations significantly influence drying rate and SMER while mushroom shape variations significantly impact SMER, rehydration ratio, and color change. The research found that chanterelle mushroom cubes dried at 56°C optimized drying conditions of chanterelle mushrooms using a heat pump dryer. This implied that increasing the surface area to volume ratio and simultaneously raising temperature fastens drying rate of mushrooms in addition to improving the final product quality.

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Nomenclature

Symbols or abbreviations	Meaning
a	Redness and greenness degree
ASAE	American Society of Agricultural Engineers
a_w	Water activity
b	Yellowness and blueness degree
C^*	Color saturation
Db	Dry basis
Dr	Drying rate
H°	Hue values
L	Lightness and darkness degree before drying
L_0	Lightness and darkness after drying
LSD	Least significant difference
Me	Equilibrium moisture content
m_i	Previous moisture content
Mo	Initial moisture content
MP	Megapixels
n	Total number of observations
OA	Orthogonal Array
Q	Total energy used, kWh
RGB	Reg green blue color threshold values
R_h	Rehydration ratio
s	Sample standard deviation
S/N	Signal to Noise
SMER	Specific Moisture Extraction Rate
W_d	Weight of dehydrated mushrooms, g
W_r	Weight of rehydrated mushrooms, g
XYZ	Tristimulus values in the three planes
y	Individual sample observation
ΔE	Color change
Δt	Time change

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