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Modeling of Moisture-Dependent Properties and Mineral Contents of Dry Mushroom

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ABSRACT

In this study, mineral contents and some physical properties, important for the design of equipments for harvesting, processing, transportation, sorting, separation and packaging of white button mushroom, *Agaricus bisporus* (Lange), were researched. Those properties were evaluated as a function of moisture content for the moisture range from 11.55 to 76.91 % dry base (d.b.) by rewetting dry white button mushrooms. In results, the average cap maximum and minimum diameter, cap height, carpophores height, geometric mean diameter, sphericity, mass weight and volume were obtained as 29.96, 23.12, 17.19, 30.48, 22.91 mm, 81.07 %, 1.08 g, and 2.93 cm^3, respectively. The bulk density, true density and terminal velocity increased from 65.24 to 115.65 kg m^{-3}, 375.8 to 394.6 kg m^{-3} and 5.77 to 8.05 m s^{-1} respectively. Whereas porosity and sphericity decreased from 82.64 to 70.69% and 78.39 to 74.9% under the increments of moisture content from 11.55 to 76.91 % d.b. in dry mushroom. Mathematical model were developed for the physical properties. Furthermore, mineral contents of dry mushroom such as N, P, K, Zn and Fe were 5.73 1.34, 3.54 %, 41.21 and 26.67 g kg^{-1}, respectively.

1. Notation

D_p	geometric mean diameter, mm
R^2	coefficient of determination
V	terminal velocity, m s^{-1}
L	cap maximum diameter, mm
H	cap height, mm
T	carpophores height, mm
W	cap minimum diameter, mm
M_c	moisture content, % d.b.
□	porosity, %
ρ_y	bulk density, kgm^{-3}
ρ_d	true density, kgm^{-3}
□	sphericity, %
M_{10}	10 carpophores mass, g

2. Introduction

Mushroom, *Agaricus bisporus*, is grown for many years all over the world. But, mushroom growing is completely different from growing green plants. Mushrooms do not contain chlorophyll and therefore depend on other plant material (the "substrate") for their food. The part of the organism that we see and call a mushroom is really just the fruiting body. Unseen is the mycelium—tiny threads that grow throughout the substrate and collect nutrients by breaking down the organic material. This is the main body of the mushroom. Generally, each mushroom species prefers a particular growing medium, although some species can grow on a wide range of materials as wheat straw, strawbedded horse manure, chicken manure and gypsum into the compost for *Agaricus bisporus* growing (Straatsma et al. 2000; Günay 2005). Compost for cultivation of *A. bisporus* is prepared from a mixture of organic materials subjected to a composting process for making it selective for growth *A. bisporus* (Colak 2004; Holtz and Scheisler 1986; Günay 2005).

Mushrooms are edible fungi of commercial importance and their cultivation has emerged as a promising agro-based land-independent enterprise. More than

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2000 species of mushrooms exist in nature but only about 22 species are extensively cultivated for commercial purposes (Manzi et al. 2001). Consumption of mushrooms has increased substantially due to their delicacy, flavor and nutritional value. Mushrooms are excellent source of several essential amino acids, vitamins (B2, niacin, and folates) and minerals (potassium, phosphorus, zinc and copper) (Manzi et al. 2001; Mattila et al. 2001; Günay 2005). A number of mushroom species are of particular interest to man by virtue of their health giving properties, and many are valued as nutritional or therapeutic sources (Mizuno 1995; Chang and Buswell 1996).

During the last decade, the worldwide cultivation of mushrooms has risen significantly and this activity now forms an important sector of the agricultural industry (Kues and Liu 2000). According to Fao Statistical record of 2005, production of white button mushroom, *Agaricus bisporus* (Lange) is 3.236.750 tones in the world. Also, in Turkey, production of white button mushroom, *Agaricus bisporus* (Lange) is about 17.000 tones (SSI 2005). In recent years, production increase rapidly in Turkey. Mushrooms can have consumed both fresh and dry mushroom. Drying is a relatively simple process that has been used for many years as a means to preserve the shelf life of products. Drying mushrooms can have benefits to both consumers and mushroom producers. Consumers would benefit by having mushroom products that could be stored for a longer amount of time making it a more convenient ingredient to be used in recipes. The mushroom producers would benefit by having a means to reduce the amount of waste from the slicing process.

The study of physical, aerodynamic and mechanical properties of food is important and essential in the design of processing machines, storage structure and processes. The shape and size are important in the separation from foreign material and the design and development of grading and sorting machineries. Bulk density, true density and porosity are important factors in designing of storage structures (Singh et al. 2010). Many researchers have determined the physical properties of other seeds, for example grains gram (Dutta et al. 1988), soybean (Screenarayanan et al. 1998), neem nut (Visvanathan et al. 1996), cumin sed (Singh and Goswami 1996), sunflower seed (Gupta and Das 1997), green gram (Nimkar and Chattopadhyaya 2001), squash seed (Paksoy and Aydın 2004), pumpkin seed (Joshi et al. 1993), melon seed (Makanjuola 1972), guna seed (Aviara et al. 1999), watermelon seed (Razavi and Milani 2006). However, literature with detailed measurements and principal dimensions with the physical properties of dry mushroom at various moisture contents has not been found.

The objective of this study, therefore, is to investigate physical properties of dry mushrooms such as linear dimensions, unit mass and volume, sphericity, densities, terminal velocity depending on the moisture. In addition, some mineral contents were determined.

3. Material and Methods

The dry mushroom **(***Agaricus bisporus* (Lange**)**) of the desired moisture levels were used for all the experiments in this study. The mushroom carpophores were harvested from Selçuk University Growing Unit in July 2009. The carpophores were cleaned manually to remove all foreign matter such as dust, dirt. Firstly, carpophores were spread out on the laboratory table 7 days. Then, the moisture content was determined by drying the carpophores at 70 C° until a constant weight was obtained (AOAC 1984). The initial moisture content of the dried mushroom carpophores was 11.55 % dry base (d.b.). The dried mushroom samples of the desired moisture levels were prepared by adding calculated amounts of distilled water, thorough mixing and than sealing in separate polyethylene bags. The samples were kept at 4 C° in a refrigerator for 7 days for the moisture to distribute uniformly throughout the sample. Before starting the test, the required quantities of the seed were allowed to warm up to room temperature (Deshpande et al., 1993, Çarman, 1996). All the physical properties of the dried mushroom were assessed at moisture levels of 11.55, 19.33, 37.58, 56.28 and 76.91 % d.b. with three replications.

3.1. Physical properties of dry mushroom

Samples of 100 dry mushrooms were randomly selected to determine the average size. Measurement of the three major perpendicular dimensions of the mushrooms was carried out with a micrometer to an accuracy of 0.01 mm (Fig. 1).

The geometric mean diameter D_p of the carpophores was calculated by using the following equation (Mohsenin, 1970):

$$D_p = (LWT)^{1/3} \qquad (1)$$

Where L is cap maximum diameter, W is cap minimum diameter and T is carpophores height (Fig.1).

According to Mohsenin (1970), the degree of sphericity Φ can be expressed as follows:

$$\Phi = [(LWT)^{1/3} / L] \times 100 \qquad (2)$$

This equation was applied to calculate the sphericity of carpophores.

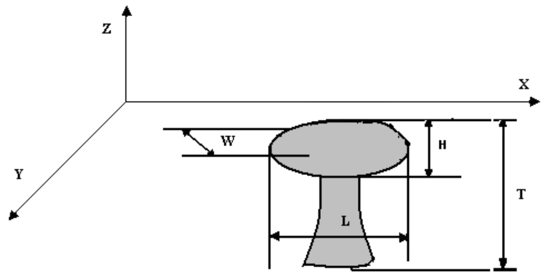

Fig 1

Axis and three major perpendicular dimensions of mushroom carpophores.

To obtain the mass, each carpophore was weighed by a chemical balance reading to 0.0001 g. The true density is defined as the ratio of the mass of a sample to its solid volume (AOAC 1984). The carpophores volume was determined using the liquid displacement method. Toluene (C_7H_8) was used in place of water because it is absorbed by carpophores to a lesser extent. Also, its surface tension is low so that it fills even shallow dips in a carpophores and its dissolution power is low (Sitkei 1986; Öğüt 1998). The bulk density is the ratio of the mass of a sample of carpophores to its total volume and it was determined with a weight per hectoliter tester which was calibrated in kg m^{-3} (AOAC 1984). The porosity of carpophores at various moisture contents was calculated by Mohsenin (1970) as follows:

$$\varepsilon = [(\rho_d - \rho_y) / \rho_d] \times 100 \quad (3)$$

Where ε is the porosity in %, ρ_y is the bulk density in kg m^{-3} and ρ_d is the true density in kg m^{-3}.

The terminal velocities of carpophores of different moisture contents were measured using an air column. For each test, a small sample was dropped into the air stream from the top of the air column, which air was blown to suspend the material in the air stream. The air velocity near the location of the carpophores suspension was measured by an electronic anemometer having an accuracy of 0.1 m s^{-1} with five replications (Joshi et al. 1993).

3.2. Colour measurement

Previous research has reported that the Hunter *L*-value is an important mushroom quality parameter (Heinemann et al., 1994). Hunter *L*, *a* and *b* values of 10 mushrooms were measured, using a Lovibond Tintometer (Type:RT 500 Colour Model Number SP 62), at each experimental intervals moisture (11.55, 19.33, 37.58, 56.28 and 76.91 % d.b.) on the centre of the mushroom cap. Three readings were obtained and averaged for each mushroom.

2.3. Determination of mineral contents

The nitrogen was calculated by Kjeldahl's method. Determination of mineral contents of mushrooms: About 0,5 g dry and ground sample was put into burning cup and 10 ml pure HNO_3 was added . The sample was incinerated in (CEM, Mars 5) Microwave oven under the 170 psi at 200 ºC temperature and solution diluted to the certain volume (25 ml) with water. Samples were filtered in filter paper, and were determined with an ICP-AES (Varian-Vista Model Axial Simultaneous) (Skujins 1998; AOAC 1984).

2.4. Statistical analysis

All properties were evaluated as functions of moisture content for the rewetted dry mushroom. Means and standard deviations were calculated and modeled to the regression analysis using Excel program. Regression equations and curves were given in results in Figures.

4. Results and Discussion

4.1. Dimensions and size of dried mushroom

The values for the mass and volume of an individual, dimensions (Fig. 1), geometric mean diameter and sphericity of dry mushroom at 11.55 % (d.b.) moisture content are given in Table 1. The average minimum and maximum cap diameter, carpophores weight, carpophores height, cap height was obtained as 15.37 to 41.18 mm, 0.255 to 2.829 g, 19.81 to 47.18 mm and 11.19 to 23.40 mm respectively.

Table 1

Means and standard errors of the mushroom dimensions at 11.55 % d.b.

Properties	Values
Cap maximum diameter, mm	29.96±3.4
Cap minimum diameter, mm	23.12±2.11
Cap height, mm	17.19±2.33
Carpophores height, mm	30.48±5.07
Geometric mean diameter, mm	22.91±1.54
Sphericity, %	81.07±6.51
Mass weight, g	1.08±0.26
Volume, cm^3	2.93±0.11

4.2. Bulk Density

The bulk density of dried mushroom at moisture levels of 11.55-76.91% d.b. varied from 65.24 to 115.65 kg m^{-3} (Fig. 2) and indicated an increase in bulk density with an increase in moisture content. Because, porosity were decreased with moisture content increased.

The statistical analysis of experimental data showed that the relation between bulk density and moisture content was significant. It is shown polynomial trend (Eqs. 4) as shown in Fig. 2 as follows:

$$\rho_y = 0.009Mc^2 + 0.0126Mc + 62,216 \quad (R^2 = 0.99) \quad (4)$$

4.3. True Density

The true density of dried mushroom in the experimental varied from 375.8 to 394.6 kg m^{-3} with the increase of moisture content from 11.55 to76.91% d.b.. The effect of moisture content on the true density of dried mushroom showed an increase (Fig. 3 and Eqs. 5):

$\rho_d = 0.1033Mc^2 - 9.0523Mc + 477.48$ ($R^2 = 0.96$) (5)

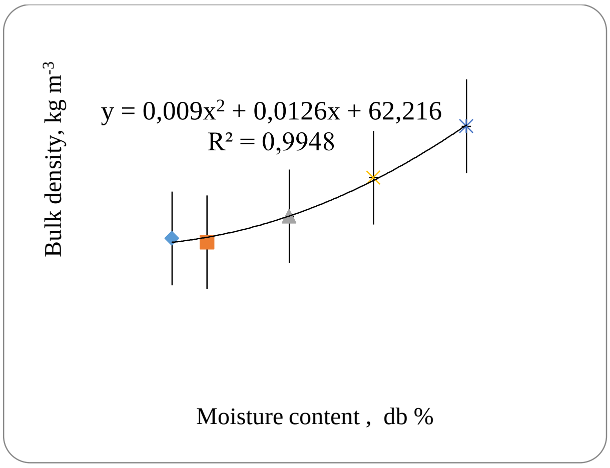

Fig 2

Effect of moisture content on bulk density.

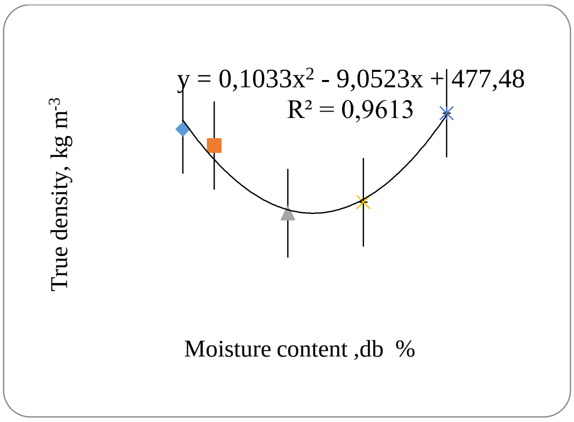

Fig 3

Effect of moisture content on true density of mushroom.

4.4. Porosity

The magnitude of variation in porosity depends on the bulk and true densities. The porosity of dried mushroom (From 82.64 to 70.69%) was found to slightly decrease with increase in moisture content from 11.55 to 76.91% shown in Fig. 4. The dried mushroom follows linear polynomial relationship with moisture content which shown in Eqs. (6):

□ $= 0.0056Mc^2 - 0.708Mc + 91.676$ ($R^2 = 0.95$) (6)

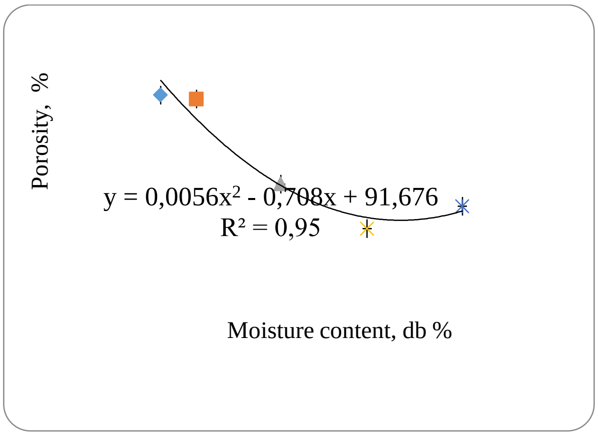

Fig 4

Effect of moisture content of porosity.

4.5. Terminal Velocity

The experimental results for the terminal velocity of the dried mushroom at various moisture levels are plotted in Fig. 5. As moisture content increased, the terminal velocity was found to increase linearly from 5.77 to 8.05 m s^{-1}. The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual mushroom per unit frontal area presented to the air stream. The values of dried mushroom follows polynomial relationship with moisture content which shown in Eqs. (7):

$V_t = 5E\text{-}05Mc^2 + 0.033Mc + 5.2748$ ($R^2 = 0.95$) (7)

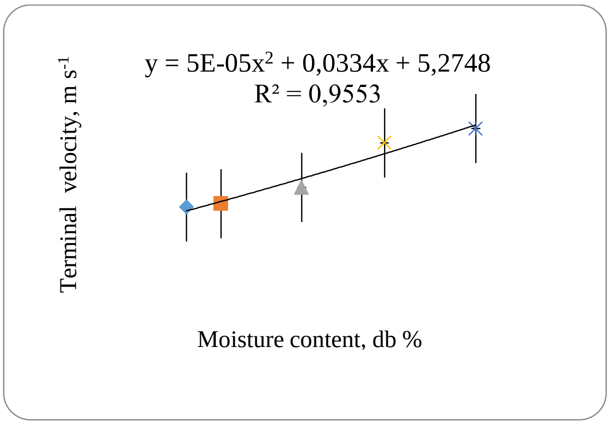

Fig 5

Effect of moisture content on terminal velocity.

4.6. Sphericity

The sphericity is a measure of a particle is the ratio of the surface area of a sphere (with the same volume as the given particle) to the surface area of the particle. The sphericity of dried mushroom decreased from 78.39 to 74.9% while the moisture content increased from

11.55% to 76.91% d.b. (Fig. 6). This variation of sphericity of dried mushroom with moisture content could be represented by the Eqs. (8).

$$\square = 0.0012Mc^2 - 0.2372Mc + 84.206 \quad (R^2 = 0.58) \qquad (8)$$

4.7. Geometric mean diameter

The geometric mean diameter of dried mushroom increased from 24.60 to 22.72mm while the moisture content increased from 11.55% to 76.91% d.b. The geometric mean diameter of dried mushroom are shown in Fig. 7 and Eqs. (9).

$$D_p = -0.0005Mc^2 + 0.0145Mc + 24.285 \quad (R^2 = 0.50) \quad (9)$$

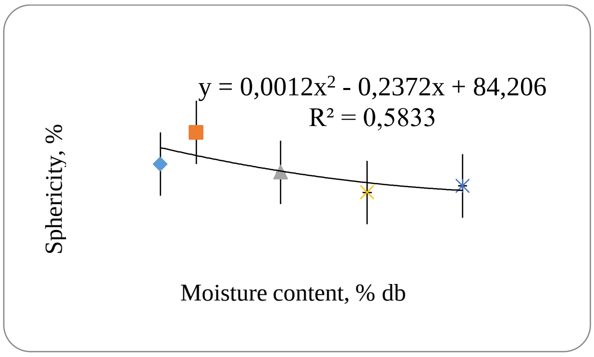

Fig 6

Effect of moisture contents on sphericity.

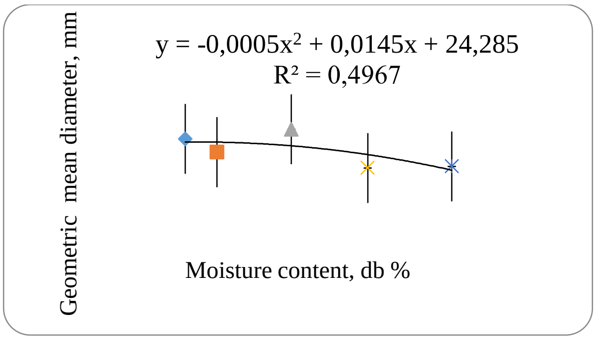

Fig 7

Effect of moisture contents on geometric mean diameter.

4.9. Mushroom weight

The mushroom weights at different moisture levels (11.55-76.91% d.b.) varied from 1.23 to 1.99 g (Fig. 8) and indicated an increase with moisture contents. Because of, the water was absorbed from the dry mushrooms.

The statistical analysis of experimental data showed that the relation between bulk density and moisture content was significant. It is shown linear trend (Eqs. 10) as shown in Fig. 8 as follows:

$$Mw = 0{,}0114Mc + 1{,}1005 \qquad (R^2 = 0{,}98) \qquad (10)$$

4.10. Colour measurement

The color of mushroom, L, a, b values, varied from 69.18-81.39; -1.37-8.07 and -0.06-23.29 respectively while the moisture content increased from 11.55% to 76.91% d.b. The color of mushroom are shown in Fig. 8 and Eqs.(11), (12) and (13). The Coefficient of Variation, C.V. (Standard deviation/ mean) was calculated for Hunter L, a, and b values. It can be seen that the variation a-value (C.V.= 77.77%), b- value (C.V.= 49.69%) and L-value (C.V.= 5.91%) with variation of moisture content. These results have given information in mushroom quality.

$$L = 0.005Mc^2 - 0.4732Mc + 80.302 \quad (R^2 = 0.67) \quad (11)$$

$$a = -0.0034Mc^2 + 0.3129Mc - 0.4 \quad (R^2 = 0.59) \quad (12)$$

$$b = -0.0077Mc^2 + 0.629Mc + 11.643 \quad (R^2 = 0.65) \quad (13)$$

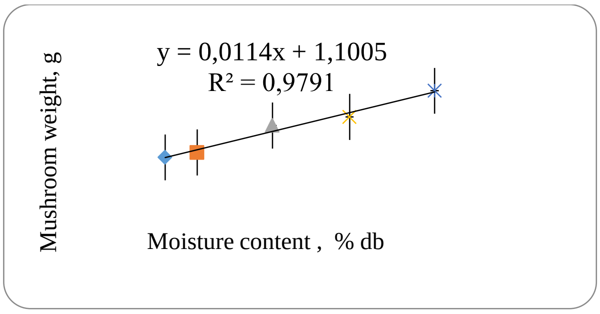

Fig 8

Effect of moisture content on mushroom weight.

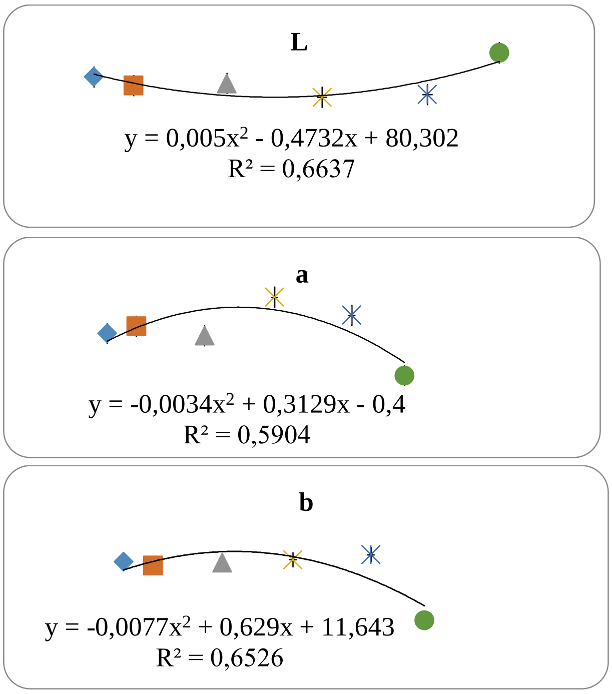

Fig 9

Average L, a, b values of mushrooms at different moisture contents

4.11. Determination of mineral contents

Mineral contents of dry mushroom are presented in Table 2. In Table 2, contents of Cu, Fe, Mn, Zn, Se, Co, Mo, B, Cd, Pb, N, P and K were determined as 43.36, 26.67, 2.91, 41.21, 2.77, 0.34, 0.43, 26.91, 0.10, 0.43 g kg^{-1}, 5.73, 1.34 and 3.54 %, respectively.

Table 2
Mineral compositions of mushroom carpophores.

Elements	g kg^{-1}
Cu	43.36
Fe	26.67
Mn	2.91
Zn	41.21
Se	2.77
Co	0.34
Mo	0.43
B	26.91
Cd	0.10
Pb	0.43
N, %	5.73
P, %	1.34
K, %	3.54

5. Conclusions

In the study, some physical properties of dry mushroom were compared as functions of moisture content (from 11.55 to 76.91% dry base) and also, mineral contents were determined. In results, the average cap maximum and minimum diameter, cap height, carpophores height, geometric mean diameter, sphericity, mass weight and volume were found as 29.96, 23.12, 17.19, 30.48, 22.91 mm, 81.07 %, 1.08 g and 2.93 cm^3, respectively. The bulk density increased from 65.24 to 115.65 kg m^{-3}, true density increased from 375.8 to 394.6 kg m^{-3}, porosity decreased from 82.64 to 70.69%, terminal velocity increased from 5.77 to 8.05 m s^{-1} and the sphericity decreased from 78.39 to 74.9% while the moisture content of dried mushroom increased from 11.55 to 76.91 % d.b..

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