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CHANGE OF PHYSICAL PROPERTIES OF GREEN BEANS DURING DRYING AND ITS INFLUENCE ON FLUIDIZATION

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ABSTRACT

Changes in the physical properties (size, particle density, bulk density, shrinkage and porosity) and fluidization behaviour of cut green beans with change in moisture content during drying were investigated using a heat pump and fluidized bed dryers. Three length:diameter ratios 1:1, 2:1, 3:1 of cut green beans were considered.

All drying experiments were conducted at 50 $\pm$ 2 ^{0}C and 13 $\pm$ 2 % RH using a heat pump dehumidifier system. Fluidization experiments were undertaken for the bed heights of 100, 80, 60 and 40 mm at 10 moisture levels in order to determine the critical moisture level of fluidization and optimum bed height for improved fluidization behaviour.

INTRODUCTION

Drying is a major food processing operation in the food industry which consumes larger amount of energy. It is a very complex process and involves mass and heat transfer processes simultaneously. Also several physical and structural changes are happening simultaneously (Fusco et al., 1991). The quality of food materials undergoing drying is not only depend on their initial quality, but also on the changes occurring during drying (Karel, 1991). Bulk density, particle density, shrinkage and porosity are important physical properties in food materials which influence fluidization properties of the dry foods. Food particles are coming in different shapes and sizes and therefore are of irregular in nature. During drying, shape and size of the products change appreciably, further influencing their particle properties (Ratti, 1994).

Shrinkage is the change in volume of the food particulate mainly as a result of removal of water. But some amount of air removal can be contributed to it, the degree of which will depend on the type of the product (Khraisheh et al., 1997). Shrinkage is important as it causes stresses and may also result in cracks (Balaban, 1989). Better understanding of the drying processes can be achieved by understanding shrinkage as it is occurring at the same time with moisture diffusion which influences moisture removal rate (Suarez and Viollas, 1991). Shrinkage of the product during drying, also influences the particle density, bulk density and porosity of the bed.

Bulk density, particle density and porosity are some of the important parameters in designing equipment pertaining to food industry. Flow resistance through beds, food storage and packaging of the products are related to bulk density and porosity (Madamba et al., 1994a). The change in density of food particulates during drying are generally modelled using empirical relations, but there are also theoretical models that are based on mass and volume (Rahman and Driscoll, 1994). Porosity of the bed changes as a result of deformations as well as shrinkage of the cells itself (Lozano et al., 1980). By selecting a suitable drying method final product porosity can thus be controlled (Krokida and Maroulis, 1997).

Several authors studied the effect of drying method and conditions on various fruits and vegetables and developed models for bulk density, particle density and porosity with change of moisture (Krokida and Maroulis, 1997, McMinn and Magee, 1997a,b, Chou et al., 1997, Wang and Brennan, 1995, Madamba et al., 1994a,b, Zogas et al., 1994, Lozano et al., 1980, Suzuki et al., 1976). Simultaneous moisture and heat transfer models were also compared with or without volume changes (Balaban, 1989). Although, several publications have dealt with changes in physical properties of various food products during drying, there are no published reports on green beans.

The objectives of this study were to determine shrinkage, density and porosity changes for cylindrical green beans with varying length diameter ratios and relate these changes to moisture content by suitable models, and to study the fluidization behaviour of the product with changing physical properties during successive drying.

MATERIALS AND METHODS

Raw material

Fresh green beans *Phascolus Vulgaris* of the variety Labrador was used in this experiment. Beans were purchased from the same supplier. Due care was taken when selecting the size of beans to ensure all were of nearly of the same average diameter (10 mm). Size variation of 10 % was allowed and was measured by a vernier caliper with an accuracy of 0.05 mm. Initially both ends of the beans were cut and only the middle portion which resembled cylindrical shape was used to prepare the required samples. Samples were prepared for three length-diameter ratios of 1:1, 2:1 and 3:1 and each experiment was repeated three times. After cutting, beans were kept in a plastic container in a cold room at 4^0 C for more than 12 hours to stabilize the moisture before experimentation.

Drying

Drying experiments were carried out in a heat pump dehumidifier drying system at 50 ± 2^0 C and relative humidity of 13 ± 2 %. Materials were placed inside the drying system on mesh trays. The trays were placed inside to achieve maximum exposure to the air flow. During drying, samples were drawn from the dryer at ten arbitrary moisture levels for fluidizing experiments and physical property measurements.

Fluidization

All fluidization trials were conducted in a batch type plexi-glass fluidizing column of 185 mm inside diameter and 1m long. The dehumidified hot air was drawn from a heat pump system coupled to the dryer. Hot air entered the material bed through a perforated plate with circular holes of 1 mm diameter (18 holes/cm^2). A second plate with 10 mm diameter holes with a diametrical pitch of 40 mm in concentrically arranged circles was placed 10 mm below the first plate to achieve even air distribution. Air flow entering the fluidized bed chamber was controlled and the differential pressure was read from a digital manometer (EMA 84 range 0 – 10 kPa) connected to a pitot tube (Dwyer DS-300). Pressure drop across the bed was measured by an U-tube manometer connected to the fluidizing chamber below the air distributor plate and above the material bed. In order to determine the optimum bed height for improved fluidization, bed heights of 100, 80, 60 and 40 mm were used. The samples used for fluidization experiment were collected in a separate container and reused for the drying experimentation.

Measurement of physical properties and moisture

Bulk density was calculated by measuring volume and weight of the samples. Volume was determined by filling a measuring cylinder by dropping samples from a constant height under gravity. Weight of the material was determined using a Sartorious electronic balance with an accuracy of 0.001 g. For each sample, the average of three readings was considered.

For the particle density and volume measurements, a known number of particles were weighed using a Sartorious electronic balance, and the volume was found by the difference of meniscus level before and after immersion of particles in paraffin in a measuring cylinder. Meniscus level difference was measured using a vernier caliper (accuracy 0.05 mm). Moisture content was determined by measuring the loss in weight by finely chopped samples held at 70^0 C under -13.3 kPa vaccum for 24 hours (AOAC, 1995).

RESULTS AND DISCUSSION

Shrinkage behaviour

Figure 1 shows the variation of volume ratio with moisture ratio for different L:D ratios. All experimental data were correlated using the following equation of the form:

$$VR = 1\text{-}B\ e^{-k\ MR} \qquad (1)$$

where VR = volume ratio, B = constant, k = constant, MR = moisture ratio (db)

A non linear regression procedure (SAS, 1985) was used to estimate the parameters in Equation 1 for different L:D ratios. The estimated parameters are shown in Table 1.

For the purpose of generalizing the relationships, value B for all three L:D were considered same and k values were linearly correlated. At zero moisture the value of VR in Equation (1) equals to (1- B). An individual analysis of the data for three different L:D ratios showed very close B value (0.93 $\pm$ 0.026). The constant B is also an indicator of maximum shrinkability of the product. It is reasonable to assume the same degree of maximum shrinkability of the product, when the moisture level of the product approaches towards zero. The k is the rate of change of shrinkage which varies with the initial L:D ratio. Most of the shrinkage was observed in radial direction.

At given B value (0.93), the variation of k with L:D ratio was found as follows:

$$k = 0.3511\left(\frac{L}{D}\right) + 1.6394 \qquad (r^2 = 0.95) \tag{2}$$

The generalized equation of the shrinkage behaviour can be written as:

$$VR = 1 - 0.93\, e^{-k\,MR} \tag{3}$$

Table 1. Estimated parameters of Equation (1)

L:D ratio	**B**	**k**	$\mathbf{r^2}$
1:1	0.93	2.0391	0.95
2:1	0.93	2.2442	0.97
3:1	0.93	2.7412	0.90

Particle density (ρ_p), bulk density (ρ_b) and bed porosity (ε)

Particle density data did not show any trend and then it was impossible to correlate to a model. This may be due to the irregular internal collapse pattern of the structure as drying proceeds. The particle density of initial material ranged from 951 kg/m^3 (965 % db moisture) to 1018 kg/m^3 (1035 % db moisture) and final dry material density ranged from 970 kg/m^3 (3.5 % db moisture) to 1179 kg/m^3 (4.1 % db moisture).

The variation of the bulk density with moisture ratio is shown in Figure 2 for all L:D ratios. For all the ratios it can be seen that the bulk density increased to a maximum and again reduced as moisture decreased. The experimental data correlated using the following equation of the form:

$$\rho_b = A_1 + B_1\, MR - C_1\, MR^2 \tag{4}$$

The General Linear Modelling procedure (GLM) (SAS, 1985) was used to estimate the parameters in Equation 4 for different L:D ratios. The estimated parameters are shown in Table 2.

Table 2. Estimated parameters of Equation (4)

L:D ratio	$\mathbf{A_1}$	$\mathbf{B_1}$	$\mathbf{C_1}$	$\mathbf{r^2}$
1:1	332.83	493.28	336.88	0.96
2:1	283.41	635.37	609.64	0.90
3:1	261.58	609.64	457.38	0.91

The bed porosity was calculated using the following equation:

$$\varepsilon = 1 - \frac{\rho_b}{\rho_p} \tag{5}$$

The variation of the bed porosity with moisture ratio is shown in Figure 3 for all L:D ratios. The experimental data were correlated using the following equation of the form:

$$\varepsilon = A_2 - B_2\, MR + C_2\, MR^2 \tag{6}$$

GLM regression procedure (SAS, 1985) was used to estimate the parameters in equation 6 for different L:D ratios. The estimated parameters are shown in Table 3.

Table 3. Estimated parameters of Equation (6)

L:D ratio	A_2	B_2	C_2	r^2
1:1	0.6978	0.6642	0.4669	0.92
2:1	0.7160	0.7160	0.5625	0.89
3:1	0.7471	0.7848	0.6193	0.89

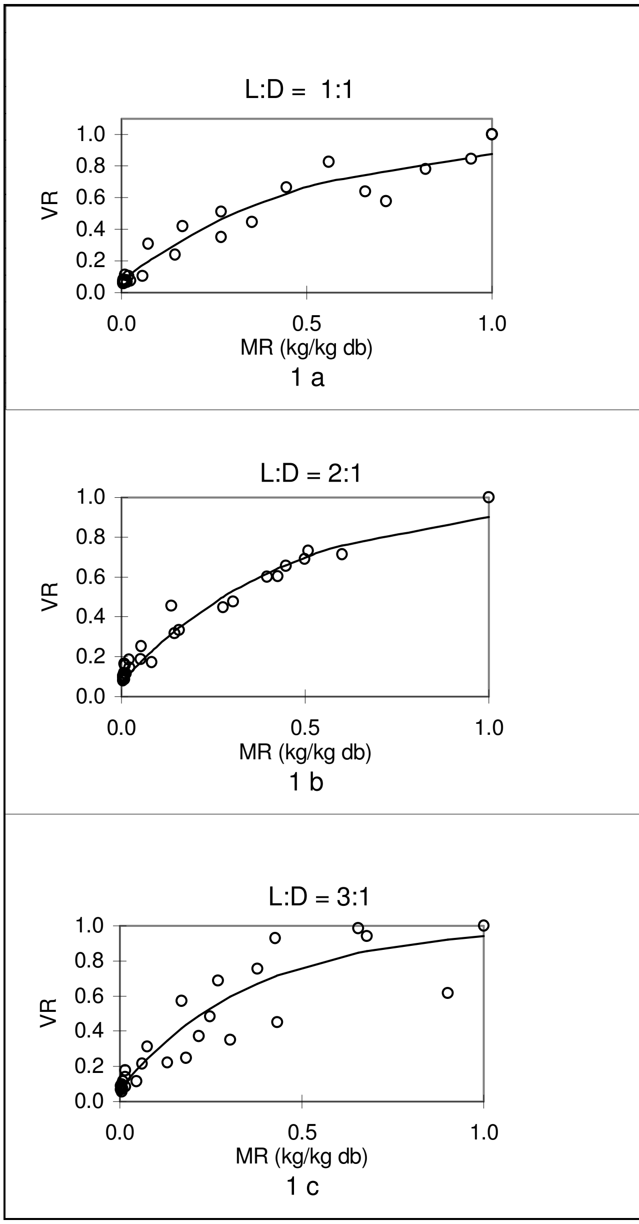


Figure 1. Shrinkage behaviour of green beans for different L:D ratios (1a, 1b, 1c) (° experimental — model)

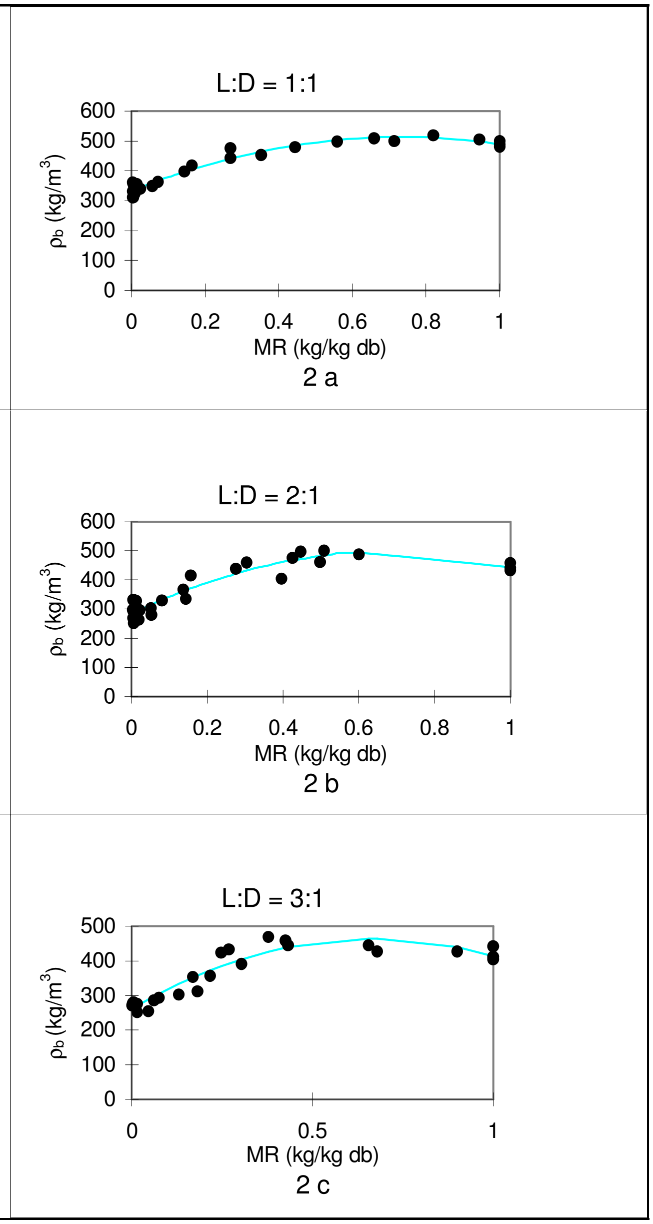
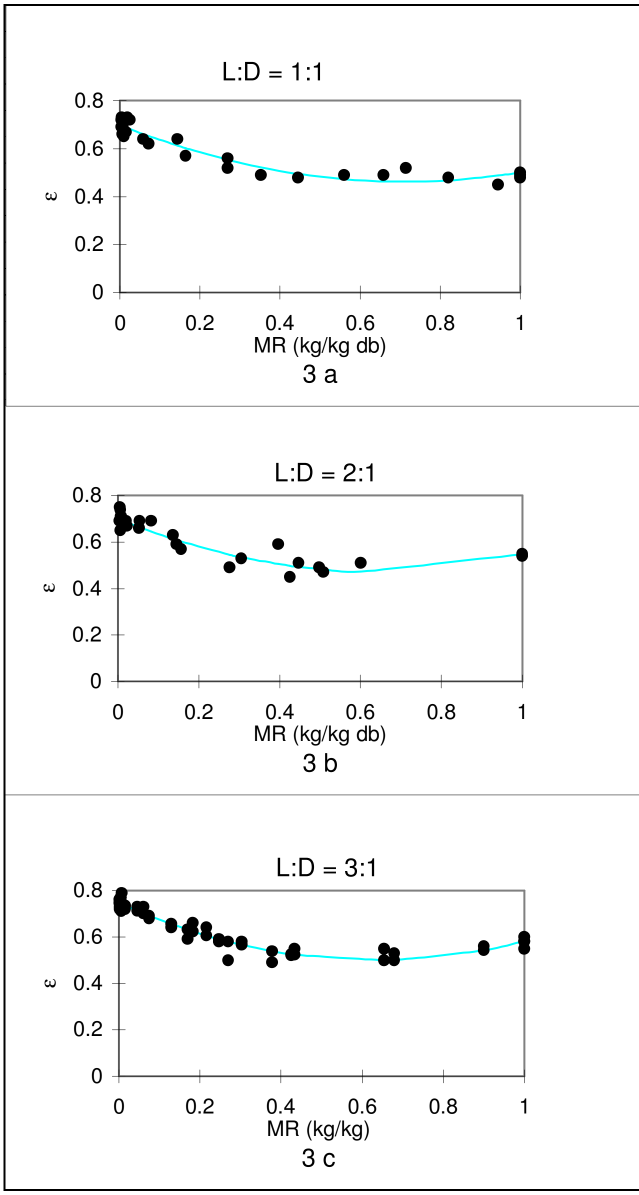


Figure 2. Bulk density variation of green beans for different L:D ratios (2a, 2b, 2c) (• experimental — model)



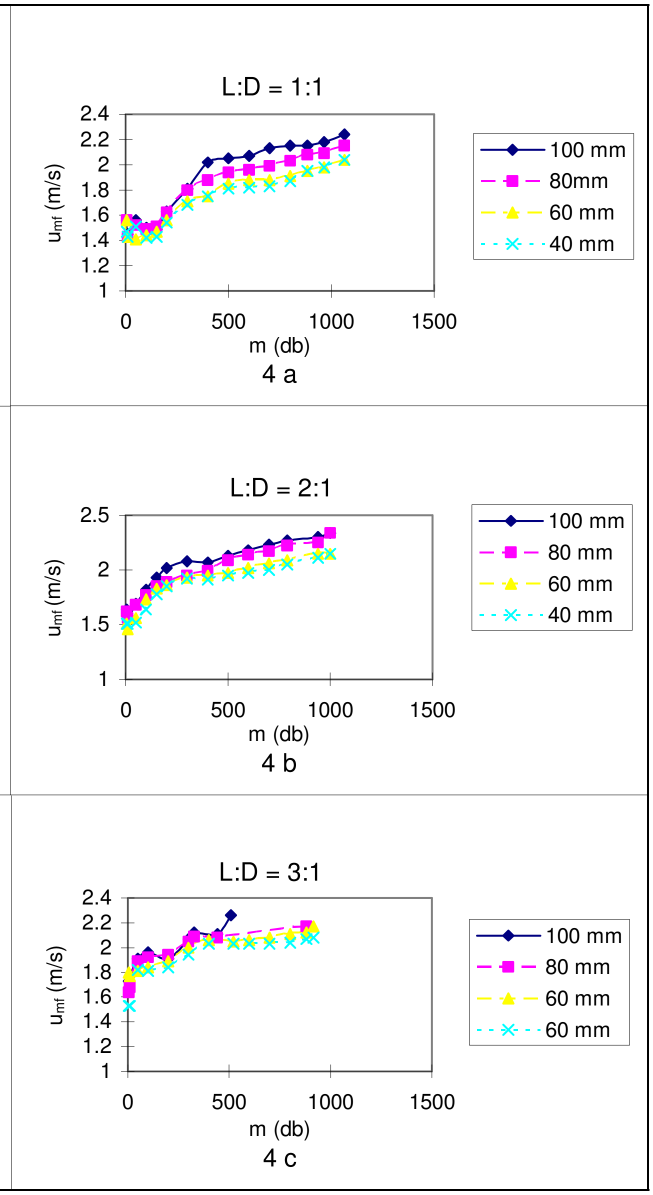


Figure 3. Porosity variation of green beans for different L:D ratios (3a, 3b, 3c) (• experimental — model)

Figure 4. Experimental minimum fluidization velocity of green beans for different bed heights and different L:D ratios (4a, 4b, 4c)

Fluidization behaviour

The criteria used to categorize the minimum fluidization was by visual observation of the bed, at the time of bed expansion followed by the particle movement. Also this value was compared with graphical variation of bed pressure drop with air velocity to determine the minimum fluidization velocity.

The variation of the minimum fluidization velocity with moisture content is shown in Figure 4 for all L:D ratios with different bed heights. At the higher moisture levels minimum fluidization was accompanied by slugging and channelling. As L:D ratio increased good fluidization could not be achieved at initial moisture levels. But good quality fluidization occured at a lower moisture values. This also varied for different L:D ratios. Good fluidization was observed at 32 %, 52 %, 60 % moisture (wb) for L:D ratios 3:1, 2:1 and 1:1 respectively. As drying proceeded, the minimum fluidization velocity decreased and hence, the energy requirement. The higher values of fluidization velocity observed at low moisture levels (< 6 % db) can be attributed to the increased particle density.

CONCLUSIONS

There is a continuous change in the physical properties of the particulates during drying, which also changes the fluidization behaviour of the particles. It is important to understand these changes, so that the air flow during drying can be controlled to achieve an optimum fluidization.

NOMENCLATURE

A_1, A_2	constants	
B, B_1, B_2	constants	
C_1, C_2	constants	
D	average diameter	(m)
L	length	(m)
VR	volume ratio	
m	moisture content dry basis	(kg/kg db)
MR	moisture ratio	
u	velocity	(m/s)

Greek

ε	porosity	
ρ	density	(kg/m^3)

Subscripts

b	bulk
mf	minimum fluidization
p	particle

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