Moisture-Depend Physical Properties of Wheat (*Triticum aestivum* L.)

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Physical properties of wheat grains (Shiraz variety) were determined as a function of moisture content in the range of 8-18 % wet basis (w.b.) using standard techniques. The average length, width and thickness were 6.78 mm, 3.45 mm and 2.84 mm, at a moisture content of 8% w.b., respectively. In the moisture range from 8 % to 18% w.b., studies on rewetted wheat grains showed that the thousand kernel weight (TKW) increased from 20.13 to 24 g, the surface area from 43.43 to 44.66 mm^2, the porosity from 0.42 to 0.44 %. Whereas the sphericity decreased from 0.6 to 0.58, the bulk density from 708.4 to 664 kgm^{-3} and the true density from 1222.4 to 1177.2 kg m^{-3} with an increase in the moisture content range of 8 –18 % w.b. The static coefficient of friction of wheat grains increased linearly against surfaces of three structural materials, namely, glass (0.33–0.4), plywood (0.46–0.55), and galvanized iron (0.34–0.54) and the static and dynamic angle of repose increased from 30.83 to 36.33 and from 37.33 to 47.33º, respectively as the moisture content increased from 8 % to 18% w.b.

Key words: Wheat, Physical properties, Moisture content, Equipment design, Shiraz variety Angle of repose

Introduction

In Iran, wheat is cultivated on 6.41 million hectares with an annual production of 13.44 million tons (Anonymous, 2003). In order to design equipment for the handling, conveying, separation, drying, aeration, storing and processing of wheat grains, it is necessary to determine their physical properties as a function of moisture content. The knowledge of some important physical properties such as shape, size, volume, surface area, thousand grain weights, density, porosity, angle of repose, of different grains is necessary for the design of various separating, handling, storing and drying systems (Sahay

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and Singh, 1994). The size and shape are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1986). The shape of the material is important for an analytical prediction of its drying behavior. (Esref and Halil, 2007). Bulk density, true density, and porosity (the ratio of intergranular space to the total space occupied by the grain) can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi Varnamkhasti *et al*., 2007). The design of storage and handling systems for buckwheat requires data on bulk and handling properties, friction coefficients on commonly used bin wall materials (galvanized steel, plywood, and concrete), and emptying and filling angles of repose (Parde *et al.*, 2003). Theories used to predict the pressures and loads on storage structures (Janssen, 1895) require bulk density, angle of repose, and friction coefficients against bin wall materials. Also the design of grain hoppers for processing machinery requires data on bulk density and angle of repose. An example of the use of various bulk and handling properties of grains in the design of storage structures is given by Singh and Moysey (1985). The angle of repose determines the maximum angle of a pile of grain with the horizontal plane. It is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but rather is peaked (Mohsenin, 1986).

Hence, current study was conducted on investigate some moisture dependent physical properties of wheat grain namely, dimensions, geometric mean, equivalent and arithmetic diameter, sphericity, thousand kernel weight (TKW), surface area, bulk density, true density, porosity, static and dynamic angle of repose and static coefficient of friction against different materials.

Notations

L	length, mm	Φ	static coefficient of friction
W	width, mm	θ_s	static angle of repose, deg
T	thickness, mm	θ_d	dynamic angle of repose, deg
TKW	thousand kernel weight, g	S	surface area, mm^2
D_g	geometric mean diameter, mm	R^2	correlation determination
D_p	equivalent diameter, mm	R_a	aspect ratio
D_a	arithmetic diameter, mm	M	moisture content, %
V	volume, mm^3	M_i	initial moisture content, %
S_p	sphericity, %	M_f	final moisture content, %
ρ_b	bulk density, kgm^{-3}	W_t	total weight of sample, g
ρ_t	true density, kgm^{-3}	ΔW_t	weight of required water, g
ε	porosity, %		

Materials and Methods

One of popular varieties of cleaned wheat (Shiraz) was obtained from Plant and Seed Institute in Tehran. The initial moisture content of seeds was determined by oven method (Tabatabaeefar, 2003) and in order to achieve the desired moisture level as 8, 12, and 18% w.b., the rewetting formula was used Eq.(1), and to allow the moisture be absorbed by samples were placed in refrigerator.

$$\Delta W_w = W_t \frac{(M_f - M_i)}{(100 - M_f)} \qquad (1)$$

A vernire caliper was used to determine length, width, and thickness of about 50 randomly selected grains of each sample. The geometric mean, D_g, equivalent, D_p and arithmetic diameter, D_a, in mm was calculated by considering prolate spheroid shape for a wheat grain and hence Eq (2), Eq (3) and Eq (4), respectively (Mohsenin, 1986).

$$D_g = (LDT)^{\frac{1}{3}} \qquad (2)$$

$$D_P = \left[L \frac{(W+T)^2}{4} \right]^{\frac{1}{3}} \qquad (3)$$

$$D_a = \frac{(L+W+T)}{3} \qquad (4)$$

The sphericity (S_p) defined as the ratio of the surface area of the sphere having the same volume as that of grain to the surface area of grain, was determined using following formula (Mohsenin, 1986).

$$S_p = \frac{(LDT)^{\frac{1}{3}}}{L} \tag{5}$$

Thousand kernel weight (TKW) was measured by counting 100 seeds and weighing them in an electronic balance to an accuracy of .001 and then multiplied by 10 to give mass of 1000 kernels.

Jain and Bal (1997) have considered grain volume, V and surface area, S may be given by:

$$V = 0.25\left[\left(\frac{\pi}{6}\right)L(W+T)^2\right] \tag{6}$$

$$S = \frac{\pi BL^2}{(2L-B)} \tag{7}$$

where

$$B = \sqrt{WT} \tag{8}$$

The aspect ratio (Ra) was calculated by (Omobouwajo *et al.*, 1999).

$$R_a = \frac{W}{L} \tag{9}$$

The true density is a ratio of mass sample of grains to its pure volume. It was determined by the toluene displacement method (Mohsenin, 1986). Bulk density is the ratio of the mass sample of grains to its total volume. It was determined by filling a predefined container with from a constant high, striking the top level and then weighing the constants (Dashpande *et al.*, 1993).

The porosity is the ratio of free space between grains to total of bulk grains. That was computed as:

$$\varepsilon = \frac{\rho_k - \rho_b}{\rho_k} \times 100 \tag{10}$$

The coefficient of static friction was determined with respect to different surfaces: plywood, glass and galvanized iron. A hollow metal cylinder (Fig. 1) of diameter 75mm and depth 50mm and open at both ends was filled with the seeds at the desired moisture content and placed on adjustable titling surface such that the metal cylinder did not touches the surface. Then the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006).

Fig. 1. Apparatus to determine empting angle of repose

The static angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the apparatus (Fig. 2) consisting of a plywood box of 140-160-35mm and two plates: fixed and adjustable. The box was filled with the sample, and then the adjustable plate was inclined gradually allowing the seeds to follow and assume a natural slope (Tabatabeefar, 2003). Finally, the data were analyzed statistically and figures were plotted using Excel software 2003.

Results and discussion

A summary of the dimensions of Shiraz wheat cultivar is shown in Table 1. The mean dimensions of about 50 samples at a moisture content of 8% w.b. were: length 6.78 mm, width 3.452 mm, and thickness 2.84 mm. All dimensions were increased with an increase in moisture content from 8 % to 18% w.b. The increasing trend in axial dimensions, with gain in moisture content, was due to filling of capillaries and voids upon absorption of moisture and subsequent swelling (Table 1).

Table1. Some physical properties of shiraz variety considering moisture content.

M.C. (%)	L (mm)	W (mm)	T (mm)	Dg (mm)	Dp (mm)	Da (mm)
8	6.78±0.38	3.45±0.24	2.72±0.21	4.04±0.20	4.06±0.23)	4.36±0.23
12	6.86±0.39	3.47±0.40	2.74±0.19	4.05±0.23	4.07±0.2)	4.37±0.20
18	7.04±0.59	3.50±0.28	2.82±0.34	4.09±0.34	4.11±0.34)	4.44±0.35

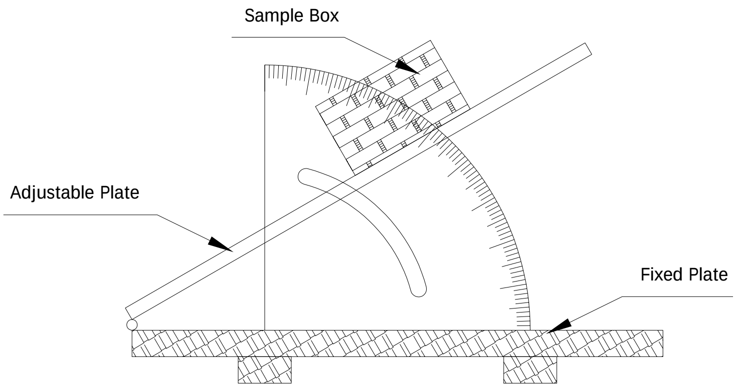

Fig. 2. Apparatus to determine coefficient of static friction

One thousand kernel weight (TKW) was increased significantly at 5% level of probability from 20.13 to 24 g as the moisture content increased from 8% to 18% w.b. (Fig. 3). Linear Relationship for one thousand kernel weight based on moisture content, M, was determined as follows:-

$$TKW= 0.39M+16.90 \quad R^2=0.99$$

A linear increase in the one thousand kernel weight as increased seed moisture content has been noted by Tabatabaeefar (2003) for wheat represented that the TKW increased linearly from 23.2 g to 39.7 g when the moisture content increased from 0 to 22 % d.b. The surface area of wheat grains increased from 43.43 to 44.66 mm^2, when the moisture content of grains increased from 8 to 18% w.b. Milani *et al*. (2007) reported an increased in surface area of cucurbit seeds of three varieties at different moisture contents in the range of 5.18 - 42.76% (w.b.).

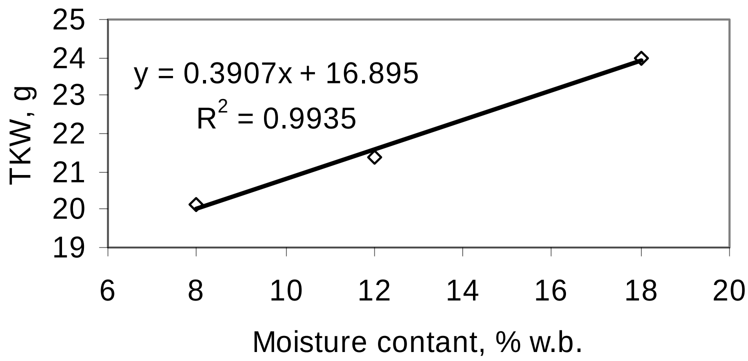

Fig. 3. Effect of moisture content on the TKW.

The sphericity of wheat grains increased from 0.58 to 0.6 with an increase in moisture content. The volume of wheat grains increased from 35.39 to 37.11 mm^3. That the positive linear relationship of volume with moisture content was also observed by Shepherd and Bhardwaj (1986) for pigeon pea. The geometric mean diameter of wheat grains increased from 4.05 to 4.09 mm and arithmetic diameter from 4.36 to 4.45 mm. in this regard Esref and Halil (2007) found similar result for white speckledred kidney bean grains. The equivalent diameter increased significantly at the 5% level of probability from 4.06 to 4.11 mm whereas aspect ratio decreased from 0.51 to 0.49. (Probability < 0.05). The values of the bulk density for different moisture levels varied from 708.40 to 664 kg m^{-3} (Fig. 4). The bulk density of seed was found to bear the following relationship with moisture content:

$$\rho_b = -4.51M + 746.70 \qquad R^2=0.98$$

A similar decreasing trend in bulk density has been reportedly and Gupta and Das (1997) for sunflower seed. Whereas Parde *et al*. (2003) reported that the standard bulk density of Koto buckwheat increased significantly from 603.90 to 612.90 kg/m^3 with an increase in moisture content from 14.8 to 15.8 %. With a further increase in moisture content, the standard bulk density decreased significantly.

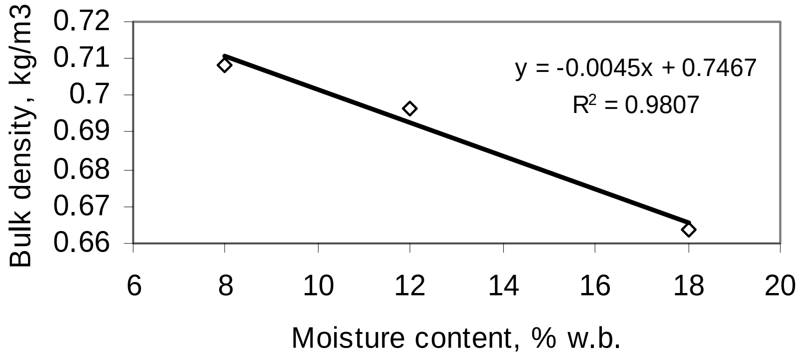

Fig. 4. Effect of moisture content on the bulk density.

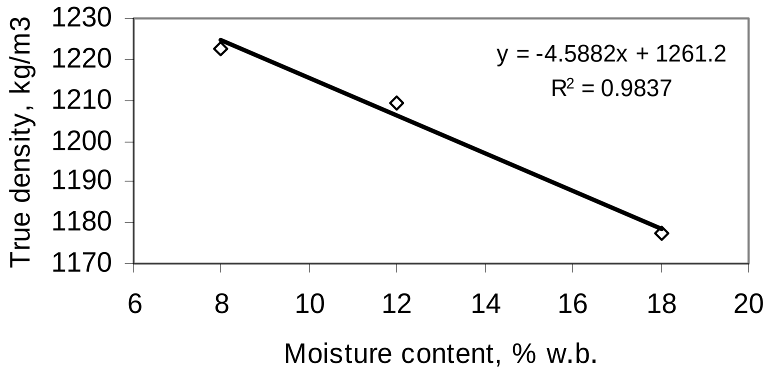

Fig. 5. Effect of moisture content on the true density.

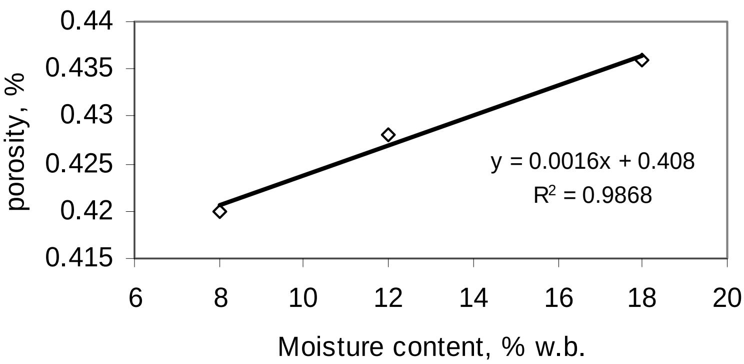

Fig. 6. Effect of moisture content on the porosity.

The true density varied from 1222.4 to 1177.2 kgm^{-3} when the moisture level increased from 8% - 18% w.b. (Fig. 5). The true density and the moisture content of grain can be correlated as follows:

$$\rho_t = -4.60M + 1261.70, \quad R^2 = 0.98$$

The results were similar to those reported by Ozarslan (2002) for cotton.

The porosity of wheat grains increased significantly at the 5% level of probability from 0.42 % to 0.44 % with the increase in moisture content from 8% to 18% w.b. (Fig. 6). The relationship between porosity and moisture content can be represented by the following equation:

$$\varepsilon = 0.01M + 0.41, \quad R^2 = 0.99$$

Baumler *et al.,* 2004, reported an increase in porosity against moisture content variations and have then evaluated the relationship between porosity and moisture content for safflower seed as:

$$e = 39.53 + 0.34M, \ R^2 = 0.93$$

The static coefficient of friction of wheat grain on three surfaces (glass, plywood and galvanized iron) against moisture content in the range 8% to 18% w.b. are presented in Fig. 7. It was observed that the static coefficient of friction increased (probability < 0.05) with increase in moisture content for all the surfaces. This is due to the increased adhesion between the grains and the material surfaces at higher moisture values. Increases of 21.21%, 19.6% and 58.8% were recorded in the case of glass, plywood and galvanized iron, respectively, as the moisture content increased from 8% to 18% w.b. at all moisture contents, the least static coefficient of friction was on glass. This may be owing to smoother and more polished surface of the glass than the other materials used. The relationships between static coefficient of friction and moisture content on glass, plywood and galvanized iron can be represented by the following equations:

$$\phi_{gla} = 0.01M + 0.28, \qquad R^2 = 0.94$$
$$\phi_{galv} = 0.02M + 0.19, \qquad R^2 = 0.99$$
$$\phi_{plyw} = 0.01M + 0.38, \qquad R^2 = 0.99$$

Similar results were found by Sahoo and Srivastava (2002) for okra.

Parde *et al.* (2003) reported that the friction coefficient against plywood, galvanized steel and concrete surfaces for the Koto buckwheat cultivar increased significantly 0.26 to 0.31, 0.25 to 0.29 and 0.38 to 0.43 respectively, with increase in moisture content from 14.8 % to 17.9 %. The authors continued for significantly increasing the moisture content variation required more than 1 %. The experimental results for the static and dynamic angle of repose with respect to moisture content are shown in Fig. 8. The values of the static and dynamic angle of repose were found to increase significantly at the 5% level of probability from 30.33 to 36.83º and from 37.33 to 47.33º, respectively in the moisture range of 8 to 18 % w.b. The static and dynamic angle of repose for wheat has the following relationships with its moisture content.

$$\theta_{st} = 0.61M + 24.90, \qquad R^2 = 0.98$$

$$\theta_{dy} = 1.01M + 29.10, \qquad R^2 = 0.99$$

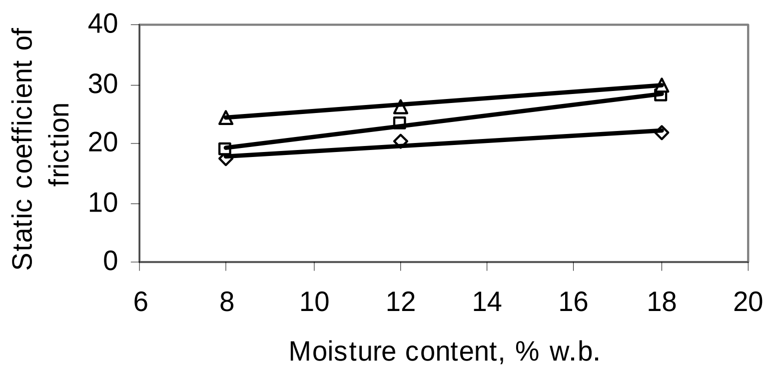

Fig. 7. Effect of moisture content on static coefficient of friction: plywood (Δ); galvanized iron (□) and glass (◊).

Tabatabeefar (2003) found that the values of dynamic angle of repose for wheat increased from 34.7 to 45° in the moisture range of 0 to 22% d.b. Parde *et al.*, (2003) reported that the emptying angle of repose for Koto buckwheat cultivar remained constant at about 23.5° from 14.8 to 15.8% mc and then increased significantly and the filling angle of repose did not differ significantly at 14.8 to 16.6% but increased significantly to 28.4° at 17.9%.

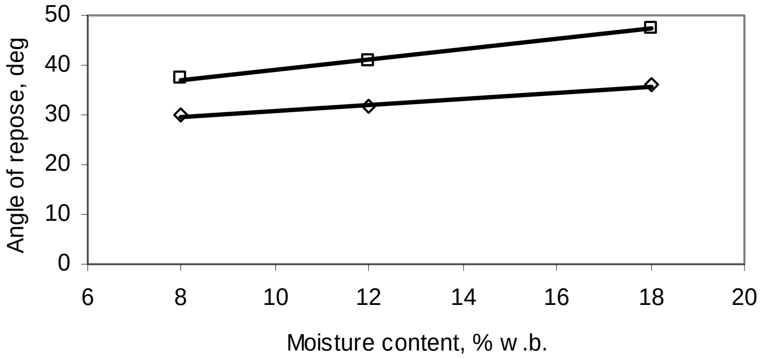

Fig. 8. Effect of moisture content on static (□) and dynamic (◊) angle of repose.

Conclusions

The various properties measured will serve as a useful tool in process and equipment design and this will go a long way in assisting to improve yield and quality of wheat grains. The following conclusions are drawn from this investigation into the properties of wheat grains, All the physical properties of wheat grains depend on their moisture contents. The moisture content of 8% (w.b.), the average length, width and thickness of 100 wheat grains were 6.78, 3.452 and 2.84 mm respectively. The average geometric mean, equivalent and arithmetic diameter, volume, surface area, sphericity, porosity, static and dynamic angle of repose and static coefficient of friction of wheat grains against different materials (glass, galvanized iron and plywood) were increased with increase in moisture content. Finally, the bulk and true density and aspect ratio was decreased with increase moisture content in wheat grains.

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References

Anonymous, Ministry of Jihad - e - Agriculture (MJA). (2003). Statistical yearbook.

Baumler, E., Cuniberti, A. Nolasco, S. M. and Riccobene, I. C. (2006). Moisture dependent physical and compression properties of safflower seed. Journal of Food Engineering. 72: 134–140.

Deshpande, S.O., Bal, S. and Ojha. T.P. (1993). Physical properties of soybean. J.Agric.Engg. Res 56: 89 – 98.

Esref, I. and Halil, U. (2007). Moisture-dependent physical properties of white speckled red kidney bean grains. Journal of Food Engineering, 82: 209–216.

Ghasemi Varnamkhasti, M., Mobli, H., Jafari, A., Rafiee, S., Heidary Soltanabadi, M. and Kheiralipour, K. (2007). Some Engineering Properties of Paddy (var. Sazandegi). International Journal of Agricultural and Biology 5: 763-766.

Gupta, R.K., and Das, S.K. (1997). Physical properties of sunflower seeds. Journal of Agricultural Engineering Research, 66: 1–8.

Jain, R.K. and Bal, S. (1997). Properties of pearl millet. Journal of Agricultural Engineering Research 66: 85–91.

Janssen, H.A. (1895). Versuche uber getreidedruck in silozellen. Z. vereines Deutscher Ingenieure 39: 1045-1049.

Milani. E., Seyed, M., Razavy, A., Koocheki, A., Nikzadeh, V., Vahedi, N., MoeinFard, M. and GholamhosseinPour, A. (2007). Moisture dependent physical properties of cucurbit seeds. Int. Agrophysics 21: 157-168.

Mohsenin, N.N. (1986). Physical Properties of Plant and Animal Materials, 2nd ed. Gordon and Breach Science Publishers, New York.

Omobuwajo. O.T., Akande, A.E. and Sann, A.L. (1999). Selected physical, mechanical and aerodynamic properties African Breadfruit (Treculia Africana) seeds. Journal of Food. Engineering 40: 241-244.

Ozarslan, C. (2002). Physical properties of cotton seed. Bio-systems Engineering 83: 169–174.

Parde, S.R., Johal, A., Jayas, D.S. and White, N.D.G. (2003). Physical properties of buckwheat cultivars. Canadian Bio-systems. Engineering, Technical Note.

Razavi, S. and Milani, E. (2006). Some physical properties of the watermelon seeds. African Journal of Agricultural Research 13: 65–69.

Sahay, K.M. and Singh, K.K. (1994). Unit Operations of Agricultural Processing. 1st ed. Vikas Publishing House Pvt. Ltd., New Delhi, India

Sahoo, P.K. and Srivastava, A.P. (2002). Physical properties of okraseed. Bio-systems Engineering 83: 441–448.

Sheperd, H. and Bhardwaj, R.K. (1986). Moisture dependent physical properties of pigeon pea. Journal of Agricultural. Engineering Research 35: 227 – 234.

Singh, D. and Moysey, E.B. (1985). Grain bin wall pressures. Theoretical and experimental. Canadian Agricultural Engineering 27: 43-48.

Tabatabeefar, A. (2003). Moisture-dependent physical properties of wheat. International. Agrophysics 17: 207–211.

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