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Determination of nutritional and mineral constituents and physical characteristics of Yubka kidney bean seeds from Talas region of Kyrgyzstan

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This study determined the nutrient ingredients and physical characteristics of kidney beans (*Phaseolus Vulgaris)* cv. Yubka cultivated in the Talas region of Kyrgyzstan. Physical properties were analyzed at moisture amount in the range of 8.4% to 30% d.b. using re-wetted kidney beans. The average, width, length, thickness, arithmetic mean diameter and geometric mean diameter were 14.2, 9.5, 7.3, 9.9 mm, 10.3 mm at initial moisture level (%8.4). The nutrient ingredients of kidney bean seeds, bearing; crude protein, crude cellulose, lower heating value, ash, organic matter, were found to be 14.4%, 3.8%, 18,67 Mj/kg, 3.86%, and 96.14% at natural moisture levels (%8.4), respectively. Mineral ingredients of kidney bean seeds, bearing; B, Cu, Fe, Mn, Zn, K, P, Ca, S and Mg, were defined at 53.5 ppm, 6.9 ppm, 66.9 ppm, 18.6 ppm, 25.06 ppm, 1.5%, 0.4%, 0.2%, 0.02%, and 0.19%, respectively.

Keywords Yubka kidney beans, Physical characteristics, Nutritional and mineral ingredients, Quality control in seed, Talas

Legumes are not widely spread in Kyrgyzstan and do not contribute largely to agricultural production. However, its share has improved significantly since the beginning of the 2000s owing to the significant rise in bean production and exports. This bean species, namely the Yubka kidney bean (*Phaseolus vulgaris* L.), cultivated in the Talas region, is an important local variety for the area and constitutes more than 90% of the legumes bred in the country. In the last few years, beans have been the third most significant export produce in Kyrgyzstan after gold-petroleum products and the first most exported agricultural crop. The country produced 80% of legume crops in the Talas region by the end of 2000. This share amplified to 92–95% in the next year and did not drop below this rate to date. Today, while bean cultivation is carried out on 530.000 decares of land in the Talas region, the maximum historical area of 550.000 decares was monitored in 2014. In addition, a yield of 1.9–2 tons per hectare is obtained. In the past decade, 90–94% of the country's legumes have been produced in the Talas region. The total agricultural land allocated to the legumes in 2016 accounted for 50.4% of the entire plowland in the Talas and 4.7% of all products in Kyrgyzstan[1].

This bean, whose scientific name is *Phaseolus vulgaris*: Yubka (кабка), plays a vital role in the area and has turned into a monoculture. Its international trade name is Rounded Caparron, and it is one of the ten most significant crops of the country[1;2].

The bean is characterized by high nutritional value and high content of the protein. With regard to nutritional value, 0,25 kg of beans equals 0,1 kg of mutton or 3 pieces of chicken eggs[1]. Half of the grains are white, and the other half is red in terms of variety. These two colors are obliquely separated, and the grains are ellipse-shaped[3]. Vegetation time is close to 80–90 days[4].

Studying its physical properties enables acquiring important and necessary engineering data to design machines for seed storage and product processing. In addition, determining seeds' physical and nutritional properties using quality control studies is very important for seed research. This work aims to determine several

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chemical, physical and nutritional features of Yubka Bean, a local variety belonging to the Talas Region, at different humidity levels.

Materials and methods

Yubka Kidney Bean (*Phaseolus vulgaris*) seeds (gifted by local grower), which is the genetic material of the Kyrgyzstan Talas region, were used for all the experiments in this research. A standard system[5] was used to determine the original humidity content of the kidney bean seeds and was found 8.4% (d. b.).

The humidity levels applied in our study (8.4%, 10%, 20%, and 30% d.b.) were achieved by adding the calculated amount of pure water dropwise and continuously stirring. The samples were then placed in separate PE bags according to the humidity level. The PE bags used are low-permeability, food-grade polyethylene bags that prevent moisture exchange. The sample bags were stored in a laboratory-type refrigerator at a constant temperature of 278 K (5 °C) for seven days to ensure a homogeneous moisture distribution throughout the sample. Humidity equilibration occurred within the bags, independent of the external environment. Before the tests, the samples were brought to room temperature under controlled conditions of approximately 22 °C to prevent chemical/physical changes due to rapid heating[6];[7];[8];[9].

Entire the physical features of the bean seeds were evaluated at water echelons of 8.4, 10, 20, and 30% d.b. with thirty repetition at each echelons.

A sample of sufficient kidney bean seeds were haphazardly chose. Measurement of the 3 main dimensions of the seeds was carried out with a micrometer with an accuracy of 0.01 mm[10].

Applying the following equation[11], the geometric mean diameter (Dp) and arithmetic mean diameter (Da) of the seeds were computed.

$$Dp = (WLT)^{1/3} \tag{1}$$

$$Da = \frac{W + L + T}{3} \tag{2}$$

Where W is the width, T is the thickness and L is the length (Fig. 1).

In accordance with Mohsenin[11], the degree of sphericity was stated as seen below:

$$\varphi = \frac{(LWT)^{1/3}}{L} 100 \tag{3}$$

The seeds were scaled on a scale with a precision of 0.0001 g to obtain the mass. True density is described as the ratio of a sample batch to the solid volume[6]. The volume of bean seeds was described applying the fluid substitution method. C_7H_8 (Toluene) was employed instead of aqua because the bean seeds absorbed it less. Toluene also has low enough surface tension and dissolving power to fill even shallow pits in bean seeds[12,13]. Bulk density is the ratio of the bulk of bean seeds to their total volume and is a water content related feature. The bulk density of bean was found by a weight per hectoliter tester calibrated in kilograms per hectoliter[6]. The porosity of bean seeds in different water content was worked out from the true and bulk densities as follows with the relationship given by Mohsen[11]:

$$\epsilon = \left(\frac{t - b}{t}\right) 100 \tag{4}$$

Where ρ_b is the bulk density in kg/m^3, ε is the porosity in % and ρ_t is the true density in kg/m^3.

Projection areas were defined by image processing technique. Digital images of seeds were taken in advance with a camera on a horizontal ground and a calibration piece of known length, placed near seeds. After

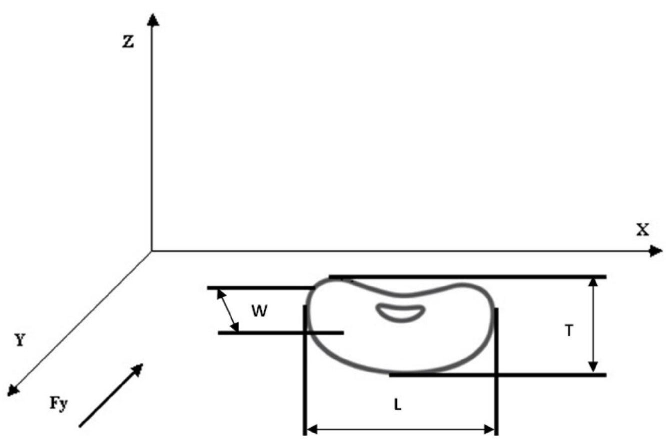

Fig. 1. Axis and three major perpendicular dimensions of bean seeds.

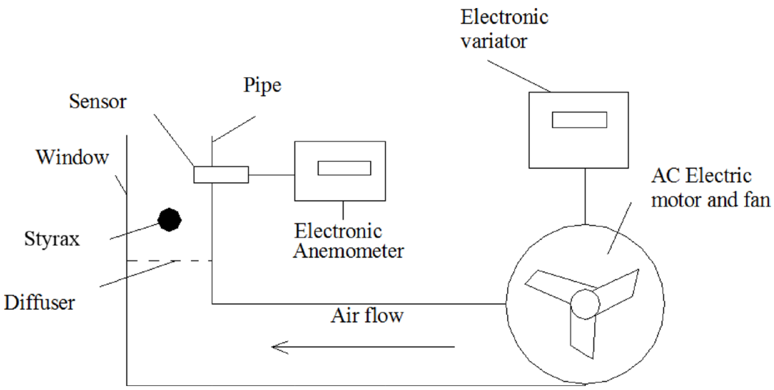

Fig. 2. Unit for measuring terminal velocity.

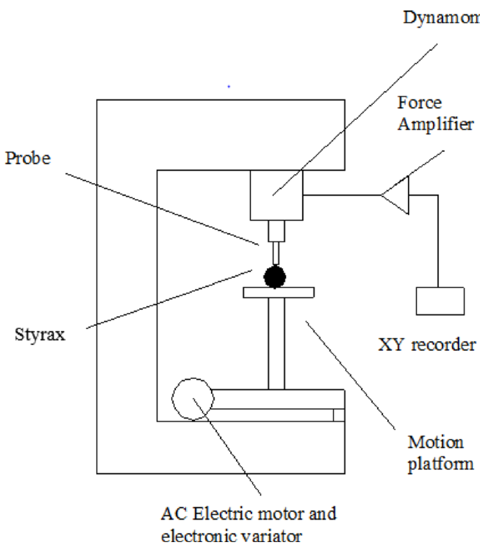

Fig. 3. Biological material test unit.

transferring these images to the computer, the projected area of kidney bean seeds was computed with the Fiji software (Version: 2.17.0, Url: ttps://imagej.net/software/fiji/).

The critical velocities of kidney bean seeds with various moisture coverage were calculated with an air pipe (Fig. 2). For the respective test, a single sample was first left in the draft from the upper of the air pipe and then blasted to stop the seed in the draft. An electronic anemometer measured the air velocity with an accuracy of 0.1 m/s when the bean seed was suspended[14]. Three repetitions were performed for every kidney bean seed.

To define the rupture strength of the kidney bean seed, we used adapted version of the biological material tester evolved by Aydın and Öğüt[15], The apparatus has 3 basic element: movable base plate-constant top plate, drive unit, and data collection system (Fig. 3). The bean seed was positioned on a movable platform and broken using a constant probe. The data collection system measured the rupture strength of the bean seeds.

The analyzes of the chemical features of the seeds we used in our research were carried out via AOAC[15]. Chemical analyses were performed on bean seeds on a dry basis before any experimental treatment or moisture adjustment, in accordance with standard procedures reported in previous studies and 4 replicates were performed. The water retention of the seeds was obtained by drying them at 70 °C until they reached a stable weightiness. The crude protein component was obtained by transform the nitrogen component via Kjeldahl's technique (6,25xN). Ash ingredient was obtained at 550 °C in an ashing furnace for 5 h. To identifing the crude fiber Tecator Fibertec System was used[16].

To determine the thermal value of fuels, IKA C 200 was used. The device measures the gross calorific values of liquid and solid samples in accordance with DIN 51,900, ISO 1928, ASTM D4809, ASTM D240, ASTM D5865, ASTM D5468, ASTM D1989, ASTM E711.

Organic matter (%) was computed by the following formula:

$$OM\ (\%) = 100 - ash(\%) \tag{5}$$

Properties	Moisture content			
	8,4%	10%	20%	30%
Length, mm	14,19 ± 1,17	14,50 ± 1,26	15,52 ± 0,91	16,60 ± 0,84
Width, mm	9,55 ± 0,82	9,52 ± 0,79	10,11 ± 0,66	10,63 ± 0,76
Thickness, mm	7,32 ± 0,65	7,22 ± 0,79	7,80 ± 0,86	8,18 ± 0,95
Geometric mean diameter, mm	9,96 ± 0,66	9,97 ± 0,70	10,68 ± 0,57	11,28 ± 0,66
Arithmetic mean diameter, mm	10,35 ± 0,69	10,41 ± 0,71	11,14 ± 0,52	11,80 ± 0,57
Sphericity, %	70,40 ± 3,71	69,00 ± 4,59	68,93 ± 4,23	68,10 ± 4,52

Table 1. Mean values and standard errors (M ± SE) of kidney bean seed dimensions at different moisture contents.

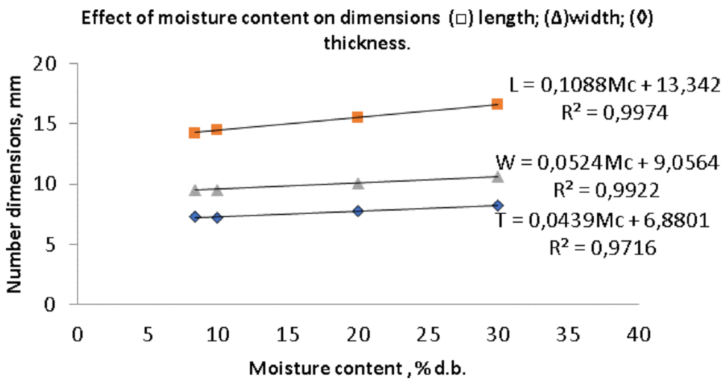

Fig. 4. Effect of moisture content on dimensions (□), length; (Δ), width; (◊), thickness.

Particulars	Ratio	Degrees of freedom	Correlation coefficient
Length/Width	1.486	98	0.429**
Length/Thickness	1.763	98	0.384**
Length/GMD,	1.424	98	0.764**
Length/AMD	1.370	98	0.854**
Length/Sphericity	0.201	98	-0.603**

Table 2. The correlation coefficient of yabgu. **significant at 1% level.

Definition of mineral amounts of bean seeds: Approximately 0.5 g of dry and milled samples were first placed in a burning cup, and 10 mL of pure HNO_3 was joined. The sample (CEM, Mars 5) was then burned in a microwave oven at a temperature of 200 °C under 170 psi and diluted to a certain volume (25 ml) with solution water. Results were defined by ICP-AES (Varian-Vista model Axial Simultaneous)[17].

Results and discussion

Basic dimensions and sizes of bean seeds

Table 1. depicts the basic dimensions (length, thickness, width), geometric mean diameter, sphericity and arithmetic mean diameter of the bean seeds at all moisture content.

The length of kidney bean seeds improved from 14.19 mm to 16.60 mm, the width of kidney bean seeds improved from 9.55 mm to 10.63 mm, the thickness of bean seeds improved from 7.32 mm to 8.18 mm, whereas the water retention of kidney bean seeds improved from 8,4 to 30% d.b. (Fig. 4).

The expression below can be utilized to indicate the relationship between the average dimensions of the seeds at 8,4% (d.b.) moisture content:

Length = 1,486 x Width = 1,938 x Thickness = 1,425 x Geometric mean diameter (GMD = 1,371 x Arithmetic mean diameter (AMD) = 0,201 x Sphericity.

The coefficients of correlation (Table 2) indicate that the Length/Width, Length/Thickness, Length/GMD, Length/AMD and Length/Sphericity rations of the seeds at 8.4% (d.b.) moisture content were discovered greatly significant. Close results were observed by Demir et al.[18] for hackberry and Haciseferogullari et al.[10]. This shows that the length, the geometric mean diameter, mass and sphericity are nearly connected to the diameters of seeds.

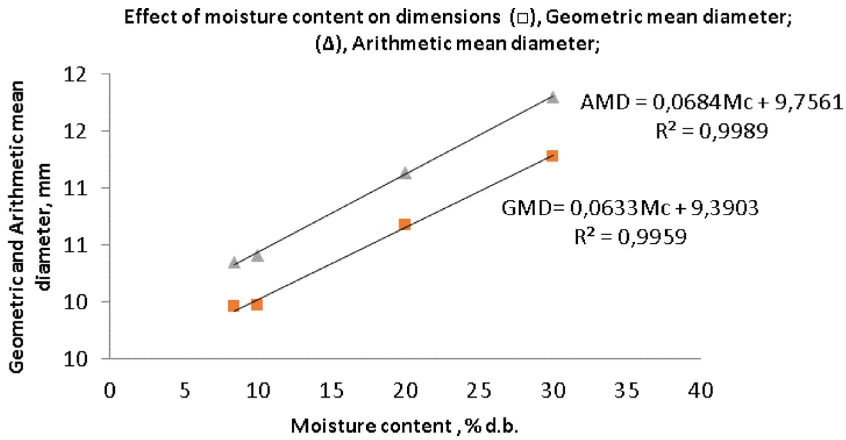

Fig. 5. Effect of moisture content on geometric and arithmetic mean diameter.

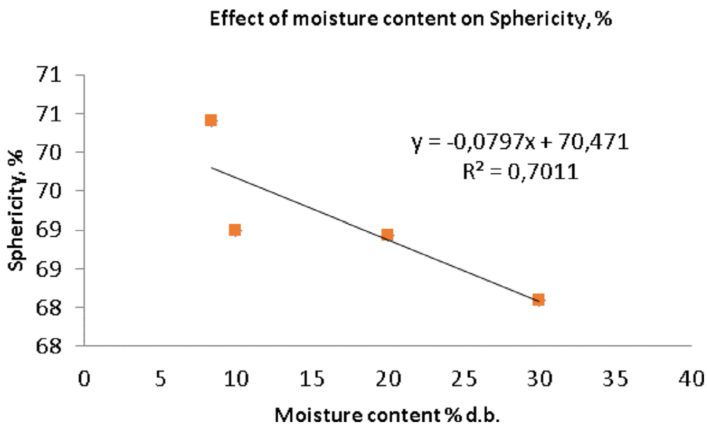

Fig. 6. Effect of moisture content on sphericity.

The geometric and arithmetic mean diameter of bean seeds improved from 9.96 mm to 1.28 mm and 10.35 mm to 11.80 mm, respectively, while the water retention of bean seeds improved from 8.4 to 30% d.b. (Fig. 5).

Sphericity

The sphericity of bean seed reduced from 70.4% to 68.1%, when the kidney bean water retention improved from 8.40% to 30% d.b. (Fig. 6). Aydın et al.[19] reported similar results for cowpea.

Bulk and true density

The bulk density of kidney bean seeds with water retention of 8.4–30% d.b. changed from 695 to 628 kg/m^3 (Fig. 7) and showed a reduction in bulk density with an enhancement in water retention. The reverse linear association of bulk density with water retention was additionally detected using pigeon peas by[20]. Similar results were conveyed by Dursun and Dursun[21] for capers and Abalone et al.[22] for Amaranth.

The true density of kidney bean seeds with moisture contents of 8.4–30% d.b. changed from 1245 to 1130 kg/m^3. It has been observed that the true density reduces with increasing water content of Kidney bean seeds. Deshpande et al.[6] also considered the linear reduction of true density with improved grain water retention in the range 8.7–25% d.b. for J.S.-7244 soybean. Parallel conclusions were documented for popcorn by Karababa[23], for hemp seed by Sacilik et al.[24], and nuts by Aydin[25].

Porosity.

Because of porosity hinge on bulk and true densities, the greatness of the change in porosity hinge only on these substances. As per the study, it was found that the porosity of the bean seed reduced slightly, with the rising in water ingredient from 8.4% to 30% d.b. (Fig. 8). Cetin[26] and Kheiralipour et al.[27] reported similar results for barbunia and wheat, respectively.

Projected area

The projected area of kidney bean seeds (Fig. 9) improved from 123.12 mm^2 to 169.80 mm^2, while the water retention amplified from 8.4 to 30% d.b.

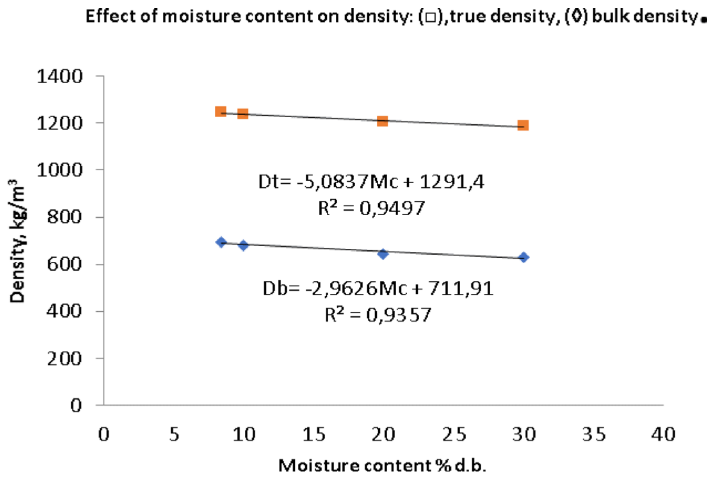

Fig. 7. Effect of moisture content on true and bulk Density.

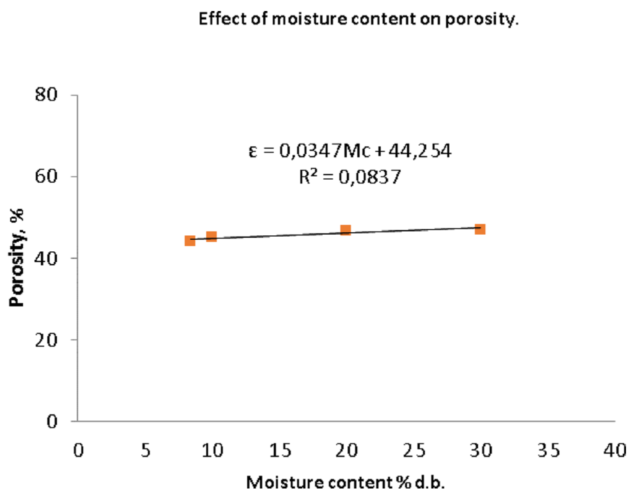

Fig. 8. Effect of moisture content on porosity.

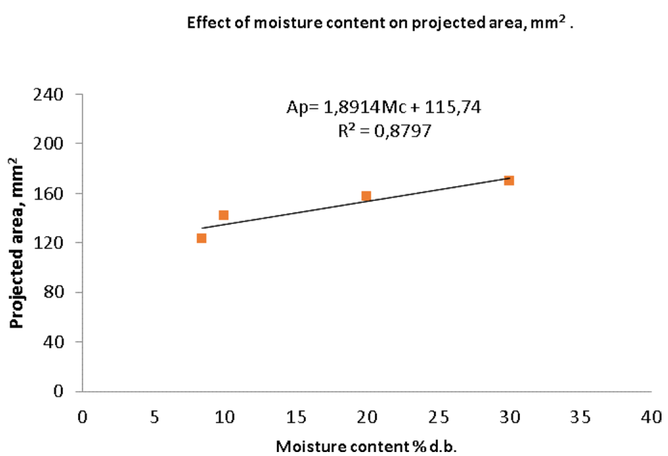

Fig. 9. Effect of moisture content on projected area.

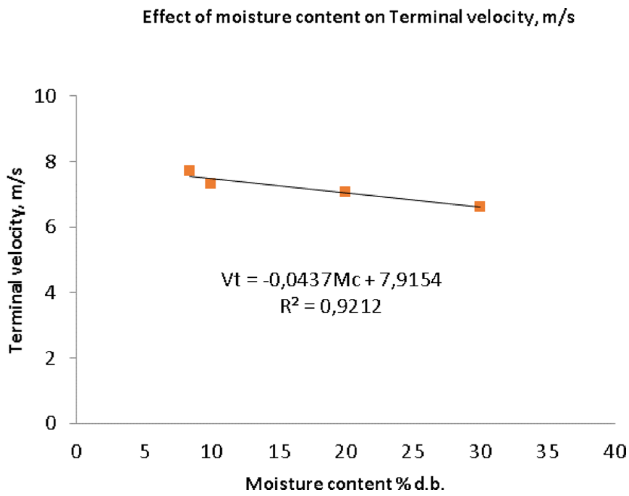

Fig. 10. Effect of moisture content on terminal velocity.

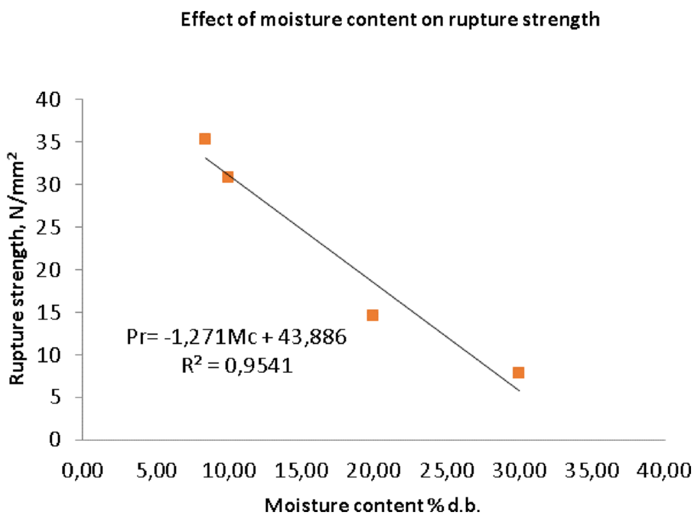

Fig. 11. Effect of moisture content on rupture strength.

The bond among projected area and water retention was considerable, and parallel results were informed for numerous other seeds[11];[12].

The correlation between the projected area and the water retention is important, and similar trainings have been described for numerous different seeds[11];[12]. Deshpande et al.[6] determined that the surface area of soybean seed improved from 0.813 to 0.952 cm^2 while the water retention improved from 8.7% to 25% d.b. Parallel propensities were observed by Abalone et al.[22] for Amaranth, Ogut[13] for white lupin, Tang and Sokhansanj[28] for lentil and Paksoy and Aydın[29] for edible squash.

Terminal Velocity.

Empirical outcomes for the terminal velocity of the bean seed at different water grades are depicted in Fig. 10. The terminal velocity of bean seed reduced from 7.7 m/s to 6.6 m/s, while the water retention of bean seed improved from 8.4 to 30% d.b. As the water content increases, the terminal velocity declines linearly.

The decrease in terminal velocity combined with the enhancement in water retention can be credited to the rise in the mass of a single seed of kidney bean per unit fore area left in the airflow. Similar conclusions are presented by Kural and Çarman[30].

Rupture strength

The outcomes obtained from the rupture strength experiments are shown in Fig. 11. During the moisture level of the bean seed improved from 8,4 to 30% d.b., The rupture strength of the kidney bean seed reduced from 35.27 to 7.84 N.

The force used to calculate the rupture strength was obtained by loading the kidney bean seeds along the Y-axis (Fy). Similar findings were presented for cowpea by Ige[31]. It was revealed in this research that the rupture

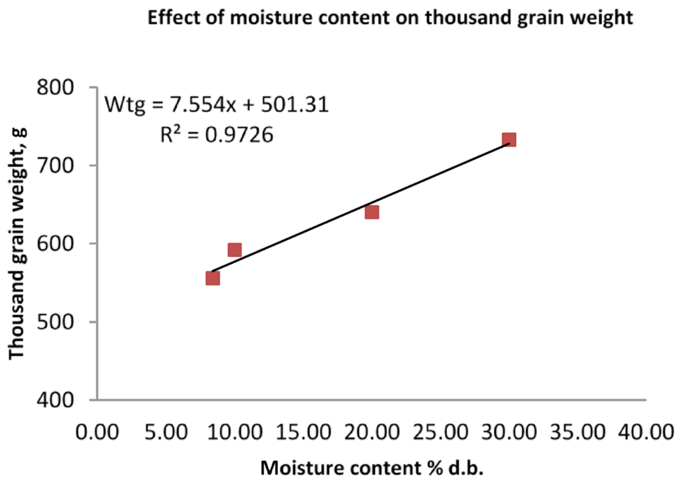

Fig. 12. Effect of moisture content on thousand grain weight

Fig. 12. Effect of moisture content on thousand grain weight.

Chemical properties of bean seeds (Dry Weight Basis)	
Moisture (%)	8,4 ± 0,46
Crude cellulose (%)	3,8 ± 0,32
Crude protein (%)	14,4 ± 0,39
Ash (%)	3,86 ± 0,362
Organic matter (%)	96,14 ± 0,351
Lower heating value (Mj/kg)	18,67 ± 0,200

Table 3. Chemical properties of bean seeds.

strength is on a large scale related to the water retention of beans. The rupture strength of bean seeds improved with an increase in water content.

Thousand-grain weight

The results of a thousand grain weight of bean seeds at varied water grades obtained by experiments are represented in Fig. 12. The outcomes demonstrated that the thousand-grain weight of the bean improved from 556.06 g to 733.21 g (31.85%), while the water retention of the bean seed improved from 8.4 to 30% d.b. Ozbek and Kayahan[9] reported similar results for Styrax.

Chemical features

Kidney bean seeds chemical composition, which examined in this study, is given in Table 3. Raw protein, crude cellulose, lower heating value, ash, organic matter values were found to be 14.4%, 3.8%, 18,67 Mj/kg, 3.86%, and 96.14% at natural moisture level (8.4%), respectively. The crude protein, carbohydrate, crude fiber, ash, and crude fat of bean varieties were in order of 24.1–25.4%, 60.8–66.4%, 5.0–6.9%, 3.4–3.9%, and 1.1–3.0%, as stated by Prinyawiwatkul et al.[32] modified from Bressani[33]. Iqbal et al.[34] indicated that ash, raw protein, crude fat, and moisture of beans were in order of, 4.2 ± 0.05 g/100 g, 24.7 ± 0.10 g/100 g, 4.8 ± 0.07 g/100 g and 9.4 ± 0.07 g/100 g. Deshpande and Damodaran[35] stated that crude energy, moisture, raw protein, crude fat, carbohydrates, and ash of beans (*Phaseolus vulgaris* L.) were, in order of 343 cal/100 g, 11.0%, 22.0%, 1.6%, 57.8%, and 3.6%.

Determination of Mineral substance contents

The nutritional components of kidney Bean seeds that we used in our research are in Table 4. These results are generally consistent with the values reported in the literature for different bean varieties. Minerals such as; P, Ca, Mg, B, Cu, Zn were available in bean seeds with levels of 0.12–0.15%, 5.00–5.50%, 0.50–0.80%, 15–20 ppm, 5–7 ppm, and 40–50 ppm, respectively, as stated by Bergmann[36]. In another study, Prinyawiwatkul et al.[32], modified from Phillips et al.[37], has been stated that; Cu, Fe, Mg, P, K, Na, Zn were the minerals available in bean seeds at concentrations in order of 8 ppm, 83 ppm, 0.18%, 0.42%, 1.11%, 0.016%, and 34 ppm. For example, compared this mineral levels with our study, the Cu and Fe contents in our study were relatively low, while the K content was higher. These differences are thought to be due primarily to the soil structure and

Mineral contents	
B	53.5 ppm
Cu	6.9 ppm
Fe	66.9 ppm
Mn	18.6 ppm
Zn	25.06 ppm
K	1.5%
P	0.4%
Ca	0.2%
S	0.02%
Mg	0.19%

Table 4. Mineral contents of bean seeds.

climatic conditions of the Talas region. Furthermore, the high potassium (1.5%) and phosphorus (0.4%) levels detected in Yubka beans enhance the nutritional value of this product, demonstrating its importance as a food source that enriches its mineral composition. Levels of trace elements such as zinc and iron in plants are crucial for human health; the obtained values indicate that this vegetable is an important mineral source in the daily diet. Compared to mineral contents reported in the literature[34]; Bergmann, 1992), Yubka beans have significant values, particularly in Fe and Zn. This demonstrates their nutritional advantage not only in the regional but also in the international market. Therefore, the obtained mineral composition data suggest that this bean can make a valuable contribution to both local agricultural production and human nutrition.

Conclution

- The mean length, thickness, width, geometric mean diameter, and arithmetic mean diameter of beans were 14.2, 9.5, 7.3, 9.9, and 10.3 mm, respectively, at 8.4% d.b. water content.
- The coefficients of correlation show that the Length/Width, Length/Thickness, Length/GMD, Length/AMD and Length/Sphericity rations of the seeds at 8.4% (d.b.) moisture content were found highly significant.
- The bulk density of beans at varied water grades changed from 694.9 to 627.7 kg/m^3, when the porosity improved from 44.2 to 47.1% as the water retention improved from 8.4 to 30% d.b.
- The true density of beans at various water degrees changed from 1244.8 to 1187.8 kg/m^3.
- The projected area of kidney beans improved linearly from 123,12 mm^2 to 169,80 mm^2 as the water content improved from 8.4 to 30% d.b.
- The critical velocity of beans reduced linearly from 7.7 to 6.6 m/s as the moisture amount improved from 8.4 to 30% d.b.
- The rupture strength was on a large scale reliant on water content. As expected, the rupture strength values of beans reduced linearly from 35.2 to 7.84 N/mm^2 as the water amount improved from 8,4 to 30% d.b.
- The thousand-grain weight values of beans improved from 556.06 to 733.21 g depending on the moisture content range (8.4 to 30% d.b.).
- The sphericity of beans reduced from 70.4 to 68.1% in the span of 13 to 35% d.b. moisture content.
- The chemical features of beans, including crude protein, crude cellulose, lower heating value, ash, organic matter, were 14.4%, 3.8%, 18,67 Mj/kg, 3.86%, and 96.14%, respectively, at natural moisture levels (%8.4).
- Mineral ingredients of kidney bean seeds, bearing B, Cu, Fe, Mn, Zn, K, P, Ca, S and Mg, were 53.5 ppm, 6.9 ppm, 66.9 ppm, 18.6 ppm, 25.06 ppm, 1.5%, 0.4%, 0.2%, 0.02%, and 0.19%, respectively.

The data from this study can be used to calculate the parameters necessary to design the agricultural mechanization tools and post-harvest product processing tools used during the cultivation of Yubka Beans. For example, rupture strength can be used in the design of the threshing unit of the harvester, and critical speed may be used to create the separation unit so that the product can be threshed and sorted appropriately. Furthermore, this data can help make the necessary calculations for the storage and transportation of the products without damage. This work can be used as a basis for future works, and more supportive results can be gathered with similar studies in the same field. While looking at our chemical and mineral composition values, it seems that Talas Bean is a local variety with a high nutritive value.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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References

1. Tilekeyev, K., Mogilevskii, R., Abdrazakova, N. & Dzhumaeva, S. Production and exports of kidney beans in the Kyrgyz republic: value chain analysis. *MPRA Paper No* **85299** (2018).

2. Asanaliev, A. & Zh Researsches on species of the genus *Phaselous* and evaluation different varieties of *Phaseolus vulgaris* in Kyrgyzstan. *Vestnik Kyrgyz Natl. Agrarian University* (1), 282–288 (2014).
3. Bodoshov, A. Determination of some physical and chemical properties of the grains beans grown in Kyrgyzstan. *Manas J. Eng.* **4**, 1–10 (2016).
4. Duishebaeva, M. K. Production and export of beans in Talas Region, Kyrgyzstan. *Reports Issyk-Kul Forum Accountants Auditors Cent. Asian Countries* (2), 100–106 (2015).
5. USDA. Official grain standards of the United States. US Department of Agricultural Consumer and Marketing Service Grain Division (Revised) (1970).
6. Deshpande, S. D., Bal, S. & Ojha, T. P. Physical properties of soybean. *J. Agric. Eng. Res.* **56**, 89–98. https://doi.org/10.1006/jaer.1993.1063 (1993).
7. Karrou, M. & Maranville, J. W. Response of wheat cultivars to different soil nitrogen and moisture regimes. *J. Plant Nutr.* **18**, 777–791. https://doi.org/10.1080/01904169509364937 (1995).
8. Kashaninejad, M., Mortazavi, A., Safekordi, A. & Tabil, L. G. Some physical properties of pistachio (*Pistacia Vera* L.) nut and its kernel. *J. Food Eng.* **72**, 30–38. https://doi.org/10.1016/j.jfoodeng.2004.11.016 (2006).
9. Ozbek, O. & Kayahan, N. Determination of some physical and mechanical properties of styrax (*Styrax officinalis* L.) grown in natural environment. *Fresenius Environ. Bull.* **29** (12A), 11209–11215 (2020).
10. Hacıseferoğulları, H., Özcan, M., Sonmete, M. H. & Özbek, O. Some physical and chemical parameters of wild medlar (*Mespilus Germanica* L.) fruit grown in Turkey. *J. Food Eng.* **69**, 1–7. https://doi.org/10.1016/j.jfoodeng.2004.07.004 (2005).
11. Mohsenin, N. N. *Physical Properties of Plant and Animal Material* revised edn (Gordon and Breach Science, 1986).
12. Sitkei, G. *Mechanics of Agricultural Materials* (Akademi Kiado, 1986).
13. Ogut, H. Some physical properties of white lupin. *J. Agric. Eng. Res.* **69** (3), 273–277. https://doi.org/10.1006/jaer.1997.0252 (1998).
14. Joshi, D. C., Das, S. K. & Mukherjee, R. K. Physical properties of pumpkin seeds. *J. Agric. Eng. Res.* **54**, 219–229. https://doi.org/10.1006/jaer.1993.1016 (1993).
15. Aydın, C. & Oğut, H. Determination of deformation energy in some biological materials. *Proceedings of the National Symposium on Mechanisation in Agriculture*, 254–264 Samsun, Turkey. (1992).
16. Association of Analytical Chemists (AOAC). Standard Official Methods of Analysis of the Association of Analytical Chemists. 14th edn, edited by S.W. Williams. Washington, DC. (1984).
17. Skujins, J. *Handbook for ICP-AES: A Short Guide To Vista Series ICP-AES Operation. Version 1.0* (Varian International AG Zug, 1998).
18. Demir, F., Doğan, H., Özcan, M. & Haciseferoğullari, H. Nutritional and physical properties of Hackberry (Celtis australis L). *J. Food Eng.* **54** (3), 241–247 (2002).
19. Aydın, C., Paksoy, M., Özer, A. & Şen, O. Some physical properties and nutritional compositions of Cowpea (*Vigna sinensis* L.) seeds. *Selcuk J. Agric. Food Sci.* **22**, 71–77 (2008).
20. Shepherd, H. & Bhardwaj, R. K. Moisture-dependent physical properties of pigeon pea. *J. Agric. Eng. Res.* **35**, 227–234. https://doi.org/10.1016/S0021-8634(86)80060-9 (1986).
21. Dursun, E. & Dursun, I. Some physical properties of caper seed. *Biosyst. Eng.* **92**, 237–245. https://doi.org/10.1016/j.biosystemseng.2005.06.003 (2005).
22. Abalone, R. Some physical properties of Amaranth seeds. *Biosyst. Eng.* **89**, 109–117. https://doi.org/10.1016/j.biosystemseng.2004.06.012 (2004).
23. Karababa, E. Physical properties of popcorn kernels. *J. Food Eng.* **72**, 100–107. https://doi.org/10.1016/j.jfoodeng.2004.11.028 (2006).
24. Sacilik, K., Öztürk, R. & Keskin, R. Some physical properties of hemp seed. *Biosyst. Eng.* **86** (2), 191–198. https://doi.org/10.1016/S1537-5110(03)00130-2 (2003).
25. Aydın, C. Physical properties of Hazel nuts. *Biosyst. Eng.* **82**, 297–303. https://doi.org/10.1006/bioe.2002.0065 (2002).
26. Çetin, M. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. 'Barbunia') seed. *J. Food Eng.* **80**, 353–358. https://doi.org/10.1016/j.jfoodeng.2006.06.004 (2007).
27. Kheiralipour, K. et al. Moisture-dependent physical properties of wheat (*Triticum aestivum* L). *J. Agricultural Technol.* **4** (1), 53–64 (2008).
28. Tang, J. & Sokhansanj, S. Moisture diffusivity in Laird lentil seed components. *Trans. ASAE.* **36**, 1791–1798 (1993).
29. Paksoy, M. & Aydin, C. Some physical properties of edible squash (*Cucurbita Pepo* L.) seeds. *J. Food Eng.* **65** (2), 225–231. https://doi.org/10.1016/j.jfoodeng.2004.01.019 (2004).
30. Kural, H. & Carman, K. Aerodynamic properties of seed crops. In *National Symposium on Mechanisation in Agriculture* (pp. 615–623). Tokat, Turkey, (1997).
31. Ige, M. T. Measurement of some parameters affecting the handling losses of some varieties of Cowpea. *J. Agric. Eng. Res.* **22**, 127–133. https://doi.org/10.1016/0021-8634(77)90056-7 (1977).
32. Priyawiwatkul, W., McWatters, K. H., Beuchat, L. R., Phillips, R. D. & Uebersak, M. A. Cowpea flour: a potential ingredient in food products. *Crit. Rev. Food Sci. Nutr.* **36** (5), 413–436. https://doi.org/10.1080/10408399609527734 (1996).
33. Bressani, R. Nutritive value of cowpea. In *Cowpea Research, Production and Utilization*, edited by S. R. Singh & K. O. Rachie, 353–359. Chichester: John Wiley & Sons (1985).
34. Iqbal, A., Khalil, I. A., Ateeq, N. & Khan, M. S. Nutritional quality of important food legumes. *Food Chem.* **97**, 331–335. https://doi.org/10.1080/10408399609527734 (2006).
35. Deshpande, S. S. & Damodaran, S. Conformational characteristics of legume 7S globulins as revealed by circular dichroic, derivative UV absorption and fluorescence techniques. *Int. J. Pept. Protein Res.* **35**, 25–34. https://doi.org/10.1111/j.1399-3011.1990.tb00717.x (1990).
36. Bergmann, W. *Nutritional Disorders of Plants*. ISBN: 3-334-60422-5, New York, USA (1992).
37. Phillips, R. D. & McWatters, K. H. Contribution of Cowpeas to nutrition and health. *Food Technol.* **45** (9), 127 (1991).

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Declarations

Competing interests
The authors declare no competing interests.

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