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Physical Characteristics and Natural Flow Rates of Dry Bean Cultivars of a Local Population Grown In Konya Province of Turkey

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ABSTRACT

In the present study, physical characteristics of some dry bean cultivars (Sarikiz, Basara and Horoz) of a local population grown in Konya province of Turkey were determined and an experimental test set up was used to investigate flow rates on different surfaces (galvanized sheet, plain sheet and painted sheet iron) and different conveyor channel angles (24^0, 28^0, 32^0, 36^0). In Sarikiz, Basara and Horoz dry bean cultivars respectively at 10.85, 9.63 and 9.12% moisture levels, average grain lengths were respectively measured as 11.51, 17.56 and 15.09 mm; average widths 7.21, 10.40 and 7.31 mm; average thicknesses as 5.11, 4.92 and 5.76 mm; average geometric mean diameters as 7.51, 9.64 and 8.59 mm; sphericity values as 0.65, 0.55 and 0.57; angle of repose values as 20.07^0, 21.99^0 and 18.53^0; thousand-kernel weights as 229.60, 514.93 and 426.67 g; bulk densities as 682.72, 696.65 and 779.17 kg m^{-3}. Static coefficient of friction values of the same cultivars (Sarikiz, Basara and Horoz) on galvanized, painted and plain sheet surface were respectively measured as 0.356, 0.441 and 0.427; 0.350, 0.428 and 0.396; 0.344, 0.401 and 0.383. In Horoz dry bean cultivar, the flow was seen on all surfaces and at all channel angles. However, there was no flow in Sarıkız and Basara cultivars on painted sheet surface at 24^o channel angle and no flow in Sarıkız cultivar on plain sheet surface at 24^o channel angle. Among the cultivars, the greatest average flow rate (1.61 kg s^{-1}) was achieved in Horoz dry bean cultivar and such a flow rate was mostly designated by grain physical characteristics and surface profile. Surface roughness influenced flow rates and the greatest flow rate on galvanized sheet surface with the lowest surface roughness was measured as 1.66 kg s^{-1}. The greatest flow rate was obtained from 36^0 conveyor channel angle (2.01 kg s^{-1}). Present findings revealed that physical characteristics of the cultivars, channel roughness and angle influenced flow rates.

1. Introduction

With the increasing world population, human nutrition has become an important issue. Decreasing agricultural lands per capita, changing consumer demands and the formation of a wide range of consumptions entail the development of several high-yield varieties. Pulses including beans, lentils, broad beans and cowpea play a great role in the solution of human nutrition-related problems.

Beans are consumed as fresh or dry bean. Beans are rich in protein and the amino acid composition of bean proteins is quite close to meat protein. Beans are also rich in carbohydrates, calcium, iron and especially phosphorus, thus have a superior position over the similar foodstuffs. On the other hand, sulphur-containing amino acid content of beans is greater than the edible pulses, thus the biological value of bean protein is high (Çavuşoğlu and Akçin 2007).

Dry bean (white bean) production areas, yield and production of Turkey and Konya province are provided in Table 1. According to 2020 data, in Konya province, dry bean farming was practiced over 185 900 da land areas and total production was 62 408 tons. Dry bean cultivated lands of Konya province constitute 18.5% of the country production area and 22.335 of country production. Yield levels are also 124% greater than the country average.

Local cultivars are highly adapted to growing the region, have a high-quality trait and mostly emerged through local selections. Today, mostly the local cultivars are grown and served to markets. These cultivars are also used in breeding studies conducted to develop new cultivars Since the local cultivars are grown with the use of conventional farming systems, the produc-

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tion of these cultivars does not comply with organic farming principles.

The physical and mechanical properties of grains play an important role in the selection of storage equipment and design of storage structures (Kashaninejad et al. 2006).

Table 1
Dry bean cultivation area, yield and productions of Turkey and Konya province (TÜİK, 2021)

	Cultivated land (da)		Yield (kg da^{-1})		Production (ton)	
Years	Konya	Turkey	Konya	Turkey	Konya	Turkey
2015	191 849	935 840	380	251	72 869	235 000
2016	202 234	898 197	367	265	69 877	235 000
2017	191 438	897 221	367	267	70 242	239 000
2018	148 111	848 045	361	259	53 439	220 000
2019	148 331	889 385	335	253	49 664	225 000
2020	185 900	1 029 857	336	271	62 408	279 518

Flow characteristics of granular products cannot be explained by fluid mechanics and hydrodynamic principles. Some agricultural products flow more easily as compared to the others. Non-uniform pressure distribution and frictional forces between the particles lead to problems such as product caking during storage, non-uniform arching and channeling etc.

The orifice shape and physical properties of the material affect the flow rate of the material. The shape of the grain and the grain shape distribution play an important role in flowability, while the unit weight affects the internal friction angle and compressibility of grain (Fitzpatrick et ark. 2004).

Many studies have focused on the material flow rate, the relationship between flow rate and material properties and the regularity of the flow in various orifices. For instance, Mohsenin (1986) investigated the factors affecting grain flow such as bin geometry, orifice shape, height / diameter ratio of orifice factors and obtained several mathematical equations which define the grain flow.

Kara and Ozturk (1997) investigated the factors that affect the flow from the orifice in the different formats of grain products and developed mathematical equations to find the flow rate of the products.

Elaskar et al. (2001) recorded a video of the flow from rough and smooth channels of sorghum and obtained velocity profiles. Researchers reported 113 % increase in velocity when the sliding surface slope angles increase from 18^0 to 38^0; they found that the maximum velocity occurred at a slope angle of 37^0; and the flow rate increased 377% when the slope angle was increased from 30^0 to 37^0.

Akar (2003) reported that natural flow rates of Sultani and Amasya okra varieties changed depending on the moisture condition, the flow angle and type of channel. The study determined that flow rates of both varieties decreased as the moisture content increased and there was no natural flow for a slope angle of 30^0 with respect to the moisture content. Furthermore, the highest flow rate values for both varieties were obtained when using a galvanized steel channel.

In Turkey, there are several ongoing investigations on the flow profiles of granular products in silos (Ozturk et al. 2008a) and design loads for nuts and corn in storage buildings (Ozturk et al. 2008b, and 2008c).

In the transport of grain products by mechanical transmission systems, the loading and unloading system transmission channels and the slope angle of the base walls of the silo are extremely important for a continual natural flow. Therefore, in this study, the natural flow rates of some dry beans varieties were determined for different flow surfaces and angles. Some physical characteristics and natural flow rates of dry beans of a local population were determined for different flow surfaces and angles.

2. Materials and Methods

Sarıkız, Basara and Horoz dry bean varieties, all of which are cultivated in Konya province, were used as the material of the present experiments.

The thousand grain weight of beans were measured by using an electronic balance with an accuracy of ±0.001 g. Initially, 100 grains were taken randomly in three replicates for each variety to measure the thousand grain weight. Dimensional properties of grains were measured by using a micrometer with ±0.01 mm accuracy. Geometric mean diameter (D_g) and sphericity (Ø) values were calculated with the use of the following equations (Mohsenin 1986).

$$D_g = (LWT)^{0.333}$$

$$Ø = (LWT)^{0.333} / L$$

Where,

D_g : Geometric mean diameter (mm)

Ø : Sphericity (-)

L : Length of grain (mm)

W : Width of grain (mm)

T : Thickness of grain (mm)

To determine the angle of repose, the materials were slowly poured on a flat surface freely. Poured materials formed a cone on the surface. The angles of repose were determined by calculating the tangent value (internal friction coefficient) of the horizontal angle of this cone (angle of repose).

Each cultivar was poured into a one-liter glass vessel with the velocity of 12 s/L. After pouring, the vessel top was leveled off, then the weight of the material was determined. The resultant weight was divided by the volume of the vessel to get the bulk density of the material.

The coefficient of static friction was measured by using sheet iron, galvanized sheet iron and painted sheet surfaces. For this measurement, one end of the friction surface is attached to an endless screw. Dry bean samples were placed on the surface and it was gradually raised by the screw. Vertical and horizontal height values were read from the ruler when the grain started sliding over the surface, then using the tangent value of that angle, the coefficient of static friction was found. Baryeh (2001) and Gezer et al (2003) have used similar methods.

The flow rate values were determined in the experimental test unit, which was constructed specifically for this purpose. The experimental test unit consists of a cylindrical feeding hopper, which has a funnel-shaped exit with a capacity of five liters; an unloading cover can be opened easily at the bottom of the hopper, and a channel conveyor. The channel conveyors which have three different surfaces and have a 0.5 m length, were used in the experiment. These channels consist of: formed steel, galvanized steel and painted steel sheet. A special structure was constructed to support the hopper and the channel. A schematic view of this experimental test unit is given in Figure 1.

During the trials, after a funnel-shaped hopper was filled with material, the unloading cover at the bottom of the storage was opened, and the digital chronometer was operated simultaneously. After all of the material entered into the channel conveyor, the chronometer was stopped and the elapsed time was determined. These values were divided by the mass of the material, and the natural flow rates were determined in three replicates

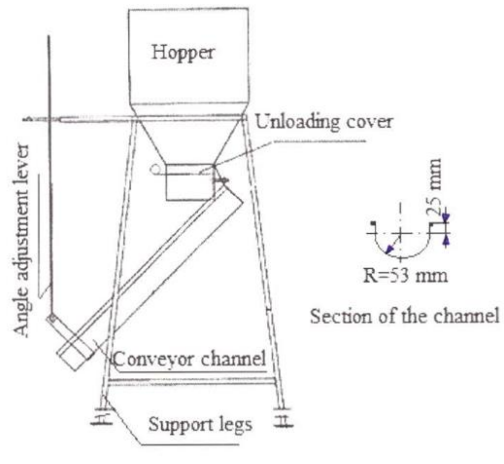

Figure 1
A schematic view of the natural flow test unit and section of the channel

There are three values to define surface roughness: Ra (the mathematical average roughness value), R_z (the measured roughness value) and Rmax (the biggest surface roughness). R_a, R_z and R_{max} values were measured by the profile-meter device (measurement range of 0-150 µm, Marsurf brand) in the three replicates.

Experimental data were subjected to ANOVA with the use of the General Linear Model of MİNİTAB 16 software. Significant means were compared with the use of Tukey's multiple range test.

3. Results and Discussion

Physical characteristics of present dry bean cultivars are provided in Table 2. The greatest grain length, width, geometric mean diameter and angle of repose values were obtained from Basara cultivar respectively with 17.57 mm, 10.40 mm, 9.64 mm and 21.99^0. In Basara cultivar, low values of thickness and sphericity (4.92 mm and 0.55) were observed. The greatest bulk density (779.17 kg m^{-3}) was obtained from Horoz cultivars and the lowest bulk density (682.72 kg m^{-3}) Sarıkız cultivar. The thousand-grain weight of Sarıkız, Basara and Horoz cultivars was respectively measured as 229.60, 514.93 and 426.67 g. The coefficient of static friction values for galvanized sheet, painted sheet and steel sheet surfaces varied from 0.344 to 0.441.

The lowest values were obtained from the galvanized sheet surface and the highest values from the painted sheet surface. Güngör and Güvenç (1996) conducted a study on registered dry bean cultivars of Turkey and reported that grains lengths varied between 8.6 mm (Karacaşehir) and 15.5 mm (Şahin-90), grain widths between 5.5 mm (Karacaşehir-90) and 7.7 mm (Şeker), grain thicknesses between 4.6 mm (Karacaşehir-90) and 6.7 mm (Şeker), and thousand grain weights between 209.1 g (Karaeaşehir-90) and 467,6 g (Yunus-90). Işık and Unal (2007) conducted a study on white speckled red kidney bean grains at 9.77% moisture level and reported geometric mean diameter as 9.38 mm and sphericity value as 0.734. Present findings on physical characteristics comply with literature findings.

Table 2
Some physical characteristics of dry bean grains

Characteristics	Sarıkız cultivar	Başara cultivar	Horoz cultivar
Moisture (%)	10.85	9.63	9.12
Lenght (mm)	11.51±0.12	17.56±0.17	15.09±0.13
Width (mm	7.21±0.07	10.40±0.08	7.31±0.06
Thickness (mm)	5.11±0.05	4.92±0.08	5.76±0.05
Geometric mean diameter (mm)	7.51±0.061	9.64±0.076	8.59±0.060
Sphericity (-)	0.65±0.003	0.55±0.004	0.57±0.002
Angle of repose (^{0})	20.07±0.56	21.99±0.71	18.53±0.98
Thousand-grain weight (g)	229.60±1.71	514.93±3.41	426.67±6.67
Bulk density (kg.m^{-3})	682.72±4.13	696.65±4.92	779.17±3.65
Static coefficient of friction			
Galvanized sheet surface	0.356±0.011	0.350±0.017	0.344±0.010
Painted sheet surface	0.441±0.015	0.428±0.011	0.401±0.013
Steel sheet surface	0.427±0.013	0.396±0.010	0.383±0.014

The changes in R_a, R_z, and R_{max} values, which determine the surface roughness of the channel conveyors, are given in Table 3. The maximum values of roughness (R_{max}), the mathematical mean roughness values (R_a) and the measured roughness values (R_z) of the galvanized sheet surface, the steel sheet surface and the painted sheet surface were found to be 6.20, 8.12 and 19.18; 1.13, 1.20 and 2.06; 4.83, 6.42, and 11.56, respectively.

Table 3
Surface roughness values

	R_{max}	R_a	R_z
Galvanized sheet surface	6.20±0.35	1.13±0.06	4.83 ±0.27
Plain sheet surface	8.12±0.74	1.20±0.06	6.42±0.30
Painted sheet surface	19.18±3.84	2.06±0.07	11.56±1.14

The natural flow rate values for different surfaces and channel conveyor angles are provided in Table 3. By increasing the channel conveyor angles, the natural flow rate values increased on all surfaces. For the channel angle of 24^o and painted sheet surface, it was observed that there was no flow in Sarıkız and Basara dry bean cultivars. Again, in the Sarıkız cultivar, there was no flow on the plain sheet surface at 24^o channel angle. Such a case was because of high static coefficient of friction (friction angle) of the grains on these surfaces.

In Horoz cultivar, grain flow on painted sheet surface (with high roughness) at 24^0 channel angle was mostly resulted from low angle of repose of the material. The angle of repose of granular materials plays an important role in design of conveyors.

Variance analysis on natural flow rates of different dry bean cultivars at different channel angles on different conveyance surfaces revealed that there were significant relationships between all parameters and levels (Table 4). The highest flow rate value was obtained as 2.26 kg s^{-1} in the horoz bean variety, on the galvanized sheet surface and at the 36 degree conveyor channel angle.

Table 4
Natural flow rates over different surfaces and at different channel conveyor angles (kg s^{-1})

	Conveyor channel angle			
	24^o	28^o	32^o	36^o
Galvanized sheet surface				
Sarıkız cultivar	$0.87\pm0.0_{jk}$	$1.50\pm0.02_{f}$	$1.87\pm0.03_{cd}$	$2.07\pm0.05_{b}$
Başara cultivar	$0.91\pm0.02_{j}$	$1.47\pm0.01_{fg}$	$1.77\pm0.05_{cde}$	$1.91\pm0.04_{c}$
Horoz cultivar	$1.26\pm0.02_{hı}$	$1.85\pm0.01_{cd}$	$2.17\pm0.01_{ab}$	$2.26\pm0.01_{a}$
Painted sheet surface				
Sarıkız cultivar	-	$1.15\pm0.01_{ı}$	$1.67\pm0.01_{e}$	$1.83\pm0.01_{cd}$
Başara cultivar	-	$1.35\pm0.01_{gh}$	1.68±0.02e	$1.84\pm0.01_{cd}$
Horoz cultivar	$1.22\pm0.01_{hı}$	$1.65\pm0.03_{e}$	$1.89\pm0.01_{cd}$	$2.06\pm0.02_{b}$
Plain sheet surface				
Sarıkız cultivar	-	$1.23\pm0.03_{hı}$	$1.82\pm0.02_{cd}$	$2.05\pm0.02_{b}$
Başara cultivar	$0.76\pm0.02_{k}$	$1.41\pm0.01_{fg}$	$1.75\pm0.02_{de}$	$1.89\pm0.01_{cd}$
Horoz cultivar	$1.26\pm0.02_{hı}$	$1.83\pm0.04_{cd}$	$2.11\pm0.04_{ab}$	$2.12\pm0.03_{ab}$

In terms of average flow rates, the greatest value was measured as 1.61 kg s^{-1} in Horoz cultivar, 1.40 kg s^{-1} in Basara cultivar and 1.34 kg s^{-1} in Sarıkız cultivar and the differences in natural flow rates of the cultivars were found to be significant ($p<0.05$). High flow rate of Horoz cultivar was attributed to grain surface profile with low angle repose and static coefficient of friction.

Increasing flow rates were observed on galvanized sheet surface with increasing conveyor channel angles. On this surface, the flow rate increase ratio in Sarıkız, Basara and Horoz cultivars was respectively calculated as 240, 210 and 179%. Such increases on painted sheet surface were respectively calculated as 159, 136 and 169% and increases on plain sheet surface were respectively calculated as 167, 249 and 168%. In terms of average flow rate, the value was measured as 1.66 kg s^{-1} on the galvanized sheet surface, 1.36 kg s^{-1} on painted sheet surface and 1.52 kg s^{-1} on plain sheet surface and the differences between average flow rates of the surfaces were found to be significant (p>0.05). Such differences were mainly attributed to surface roughness values. The greatest average surface roughness value was observed on galvanized sheet surface (1.13 µm) and the lowest on painted sheet surface (2.06 µm) (Table 3).

In terms of flow rates, there were significant differences between conveyor channel angles. The average flow rate at 36^0 channel angle was measured as 2.01 kg s^{-1} (p>0.05). High channel angles increased flow rates and decreased flow depths. Elaskar et al. (2003) indicated that flow rate and maximum stable flow depth of sorghum grains exhibited almost a linear relationship with channel angle.

4. Conclusion

There were significant differences in physical characteristics of dry bean cultivars of a local population grown in Konya province. There was no flow in Sarıkız and Basara cultivars on painted sheet surface at 24^o channel angle and no flow in Sarıkız cultivar on plain sheet surface at 24^o channel angle. Therefore, to achieve flow on these surfaces, a greater channel angle than the static coefficient of friction (friction angle) should be selected. Such an issue should be taken into consideration especially for surfaces with high surface roughness. Present observations revealed that periodical cleaning of the channel base will lead to greater flow rates. In the present study, experimental observations were presented without a theory. Further research is recommended for velocity profiles and flow characteristics of granular materials.

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