

Research paper

Physical and engineering properties of chickpea (*Cicer arietinum* L.) for planter design

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ABSTRACT

The design of a chickpea planter and its optimum performance requires physical and engineering properties of the grain varying with cultivars. Such properties include size, shape, mass, density, static friction coefficient, and repose angle etc. The cultivars viz. JG 16, HC 5, KWR 108, IPC 4-1, IPC 5-62, DCP 92-3, IPC 4-98 and JG 14 were investigated at 11.0±1.0 per cent moisture content using standard methodology. The grain size was presented in terms of major, intermediate, minor, and geometric mean diameters as 8.49-9.78, 5.91-7.23, 5.88-6.94, and 6.68-7.89 mm, respectively. The shape of the grain was presented in terms of sphericity which ranged from 0.78-0.81. The thousand seed mass, bulk density, and true density were 198-338 g, 830-880 kg m⁻³, and 1310-1350 kg m⁻³, respectively. The static friction coefficient was the least against aluminium followed by galvanised iron and mild steel surfaces with respective ranges of 0.37-0.40, 0.41-0.45, and 0.52-0.56. The angle of repose ranged from 26.4-27.7 degrees. There was a significant varietal difference in different physical and engineering properties of chickpeas except true density and angle of repose, where the difference was non-significant.

Key words: Angle of repose, Bulk density, Coefficient of static friction, Geometric mean diameter, Sphericity, True density

INTRODUCTION

Pulses are a rich source of protein and are essential for the nutritional security of the vegetarian population in the country. India is the largest producer, consumer and processor of pulses in the world. India has achieved total pulses production of 25.72 mt in a total area of 28.83 m ha during 2020-21. As per the fourth advance estimate of the production of pulses for the year 2022-23, the country could achieve a record production of pulses recording an all-time high production of 27.69 mt of pulses. Major pulses of the country include chickpea, pigeonpea, lentil, greengram, blackgram, horsegram, cowpea, etc. Madhya Pradesh is the largest pulses producing (5.30 mt) state followed by Rajasthan (4.31 mt), Maharashtra (4.30 mt), and Uttar Pradesh (2.56 mt) in the year 2020-21. Chickpea is the major pulse crop with 11.99 mt of production in a 9.85 m ha area, followed by pigeonpea with 4.28 mt of production in a 4.80 m ha area. In case of chickpea, Madhya Pradesh is the largest producer (3.13 mt) followed by Maharashtra (2.37 mt) and Rajasthan (2.32 mt). The productivity of pulses increased from 441 kg ha⁻¹ in the year 1950-51 to 892

kg ha⁻¹ in the year 2020-21 and in the same period, the productivity of chickpea increased from 482 kg ha⁻¹ to 1217 kg ha⁻¹ (Anonymous, 2023). Various production technologies, varietal interventions, and government policies played an important role in it.

Farm power availability in India has increased from 0.293 kW ha⁻¹ during 1971-72 to 2.24 kW ha⁻¹ during 2016-17 and tractorisation of Indian agriculture (tractor power 1.324 kW ha⁻¹) contributed approximately 60% to it (Anonymous, 2021). Previously, work on the mechanization of chickpea has been conducted to know the effect of planting methods, seed rate, and irrigation (Kumar *et al.*, 2015), performance evaluation of mechanical planters for the planting of chickpea and pigeonpea (Singh *et al.*, 2012), and manually operated no-till drill for chickpea (Singh *et al.*, 2013) at ICAR-IIPR, Kanpur. Though various farm operations have been mechanized, mechanization in pulses is still at a nascent stage. Overall mechanization in pulses is only 34% which is comparatively lower compared to wheat (63%) and rice (45%) (Mehta *et al.*, 2019). Various pre- and post-harvest operations have been tried for mechanizing chickpea cultivation.

However, the crop-specific complete package is still missing. Planting is one of the farming operations needed for timeliness with minimum dependence on laborers and avoiding drudgery. It has been reported to affect the cropping yield positively through the uniform distribution of seeds (Murray *et al.*, 2006). Uniformity in seed distribution can be ensured through precisely designed planters maintaining row-to-row and seed-to-seed distance. In this context, Singh *et al.* (2007) revealed the adverse effects of highly populated and non-uniformly distributed seeds on the output of the crops. The machine design, its capacity and optimum performance are affected by the physical and engineering properties of the grain. Following the facts, cotton seed (Ramesh *et al.*, 2015) and different rice cultivars (Rajaiah *et al.*, 2015) were studied in the recent past. Such properties have also been investigated for Giza 3 and Giza 195 cultivars of chickpea seeds (Eissa *et al.*, 2010). Konak *et al.* (2002) also studied the properties of chickpea seeds as a function of moisture content. However, a detailed study is still missing as variations in properties with cultivars. Their wide variation among cultivars of the same commodity necessitates the study to have actual ranges for designing the precisely working planters. Keeping aforesaid facts under consideration, the physical and engineering properties of chickpea seeds have been studied for determining various parameters of the planter.

MATERIALS AND METHODS

Chickpea grain of different cultivars (Fig. 1) viz. JG 16, HC 5, KWR 108, IPC 4-1, IPC 5-62, DCP 92-3, IPC 4-98, and JG 14 were collected from the Division of Crop Improvement, ICAR-Indian Institute of Pulses Research, Kanpur.

The grains were dried in a tray drier, cleaned, weighed, moistened, and conditioned to attain 11.0 ± 1.0 per cent moisture content. Engineering properties such as size, shape, density, porosity, coefficient of static friction, and angle of repose were calculated following Deo *et al.* (2019), Prakash *et al.* (2019) and Mohsen (1986) for agricultural materials. The measurement of density, static friction coefficient, and angle of repose were replicated three times to present their mean values. The grain size was measured using a digital vernier caliper with the least count of 0.01 mm and presented as the average of 30 samples for each of the variety in 3 replications. The arithmetic and geometric mean diameters were determined as the arithmetic and geometric means of dimensions, respectively. Sphericity was

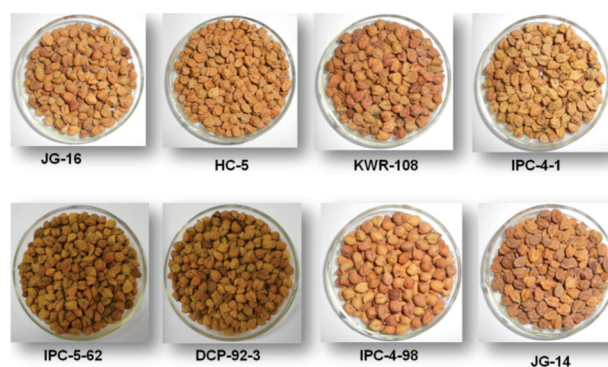


Fig. 1. Different varieties of chickpea taken for the study

calculated as the ratio of geometric mean and major diameters. The Bulk Density (BD) of the seed was measured using a wooden box of known weight (kg) and volume (m^3). The test sample was poured gently into a wooden box while keeping the surface levelled after filling. The straight edge was carefully passed across the top of the box to remove excess after piling the grain in the box. The sample weight (kg) was obtained as the difference in box weight with the sample and the same for the empty box. The true density (TD) of the seed was determined by the toluene displacement method. The pre-weighed sample was immersed in a volumetric flask containing toluene liquid. The increased volume of toluene was recorded for each sample. True density was calculated as the ratio of sample mass (kg) and its volume (m^3) (Deo *et al.*, 2019). Thus, bulk density and true density were calculated as equations 1 and 2, respectively. Observations were taken as a mean of three replications for each treatment.

$$BD = \frac{\text{Sample mass}}{\text{Box volume}}, \text{ kg m}^{-3} \quad \dots (1)$$

$$TD = \frac{\text{Sample mass}}{\text{Displaced volume of toluene}}, \text{ kg m}^{-3} \dots (2)$$

The angle for static friction coefficient against surfaces of mild steel, galvanized iron, and aluminium was measured for chickpea seeds using the inclined plane method (Prakash *et al.*, 2019; Singh *et al.*, 2010). An open-ended plastic cylinder was filled with the seed and kept horizontally on the surface. The slope was increased gradually and the angle (α) at the impending slide was recorded. The procedure was repeated 10 times and the mean value was calculated in three replications. The angle of repose (θ) was determined as the angle formed after opening one of the sides in a cubical box of $200 \times 200 \times 200$ mm filled with seed (Prakash *et al.*,

2019). The angle of repose was calculated using the following equation (3). The experiment was repeated 10 times to determine the mean angle of repose of the seed for three replications.

$$\theta = \arctan(\text{slope}), \text{ degree} \quad \dots (3)$$

RESULTS AND DISCUSSION

Physical and engineering properties of different varieties of chickpeas namely JG 16, HC 5, KWR 108, IPC 4-1, IPC 5-62, DCP 92-3, IPC 4-98, and JG 14 have been studied for the determination of parameters for the design of planter. Standard procedures were followed to measure different physical and engineering properties. Different parameters like length, breadth, thickness, geometric mean diameter, sphericity, bulk density, true density, angle of repose, and coefficient of static friction were calculated using different apparatus.

Size

Grain size is represented in terms of its major (length), intermediate (breadth), minor (thickness) diameters, and geometric mean. Their respective values were in the range of 8.49-9.78, 5.91-7.23, 5.88-6.94, and 6.68-7.89 mm for different varieties of chickpea. In the case of length, IPC 4-98 had the highest mean length (9.78±0.03 mm) and DCP 92-3 showed the least mean length (8.49±0.10 mm). HC 5, IPC 5-62, and DCP 92-3 had mean length values lower than 9 mm whereas, JG 16, KWR 108, IPC 4-1, IPC 4-98, and JG 14 had higher values than 9 mm. There was a significant difference among the length of different varieties (Table 1). In the case of breadth, HC 5 showed the least value (5.91±0.04 mm) and

IPC 4-98 had the highest mean breadth of 7.23±0.02 mm. The minor dimension (thickness) was observed lowest for DCP 92-3 (5.88±0.07 mm) and highest for IPC 4-98 (6.94±0.04 mm). Overall, geometric mean diameter was in the range of 6-7 mm for DCP 92-3, HC 5, and IPC 5-62 and 7-8 mm for JG 16, KWR 108, IPC 4-1, IPC 4-98, and JG 14. There was a significant difference in all three dimensions and GMD of different varieties of chickpeas under study (Table 1). The size of the cell of the metering mechanism of the planter could be taken as 7-8, 8-9, and 9-10 mm by giving some clearances. In the past, Eissa *et al.* (2010) revealed the range of length, breadth, thickness, and GMD 7.92-8.14, 6.10-6.37, 6.43-6.84, and 6.77-7.08 mm for Giza 3 and Giza 195 varieties of chickpea at moisture ranging from 11.6 - 25.4% (db). Konak *et al.* (2002) reported it as 9.342, 7.722, 7.752, and 8.358 mm, respectively for chickpea seeds. However, it was not investigated as a function of cultivars. The length, width, and thickness of mothbean (Nimkar and Chattopadhyay, 2001) was lower than the same for chickpea. Their respective values were 4.21, 3.17 and 3.08 for mothbean (Nimkar and Chattopadhyay, 2001). Islam *et al.* (2001) reported length, breadth, and thickness in the range comparable to our values with 7.968-8.758, 5.864-6.554 and 5.713-6.359 mm for chickpea, at moisture content ranging from 10.83 to 31.20 per cent (db). The grain size guides designing the cell size of the metering plate for the metering mechanism of the planter. Rajaiah *et al.* (2015) also mentioned the application of seed size in determining the cell diameter for seed metering. Similarly in the case of the urea briquette applicator, a kind of briquette planter, the urea briquette size played a significant role in designing the cell size of the metering plate (Deo *et al.*, 2021a and 2021b).

Table 1. Size, shape and gravimetric properties of chickpea seeds

Variety	L (mm)	B (mm)	T (mm)	GMD (mm)	Sphericity	TSM (g)	BD (kg m ⁻³)	TD (kg m ⁻³)
JG-16	9.01±0.11	6.42±0.08	6.30±0.05	7.08±0.09	0.787±0.003	237±3.2	847±03	1320±10
HC-5	8.65±0.03	5.91±0.04	6.12±0.02	6.78±0.02	0.780±0.006	213±2.5	853±03	1330±10
KWR-108	9.42±0.04	6.93±0.05	6.63±0.05	7.56±0.05	0.800±0.006	295±1.9	860±00	1333±09
IPC-4-1	9.28±0.08	6.58±0.05	6.48±0.05	7.34±0.06	0.787±0.003	253±4.0	847±03	1330±14
IPC-05-62	8.73±0.02	6.03±0.04	6.06±0.02	6.83±0.03	0.780±0.006	210±1.7	850±00	1313±03
DCP-92-3	8.49±0.10	6.00±0.07	5.88±0.07	6.68±0.07	0.787±0.003	198±1.5	870±00	1350±15
IPC-04-98	9.78±0.03	7.23±0.02	6.94±0.04	7.89±0.02	0.807±0.003	338±1.5	880±06	1310±15
JG-14	9.75±0.02	6.68±0.03	6.72±0.03	7.59±0.03	0.783±0.003	292±2.1	830±00	1313±07
Min	8.49	5.91	5.88	6.68	0.780	198	830	1310
Max	9.78	7.23	6.94	7.89	0.807	338	880	1350
F-value	58.15*	85.39*	67.30*	115.24*	4.71*	406.92*	28.50*	0.54**
CD (p=0.05)	0.197	0.155	0.134	0.126	0.013	7.441	0.009	N/A
SE(m)	0.065	0.051	0.044	0.041	0.004	2.461	0.003	0.018
SE(d)	0.092	0.073	0.063	0.058	0.006	3.480	0.004	0.026
CV	1.237	1.375	1.199	0.984	0.968	1.674	0.585	2.401

Where, L=Length (mm); B=Breadth (mm); T=Thickness (mm); GMD= Geometric Mean Diameter (mm); TSM= Thousand Seed Mass (g); BD= Bulk Density (kg/m₃); TD= True Density (kg/m₃) and * indicates 5% level of significance, and ** indicates not significant

Shape

The shape of the grain indicates the relative values of their dimensions and is usually presented in terms of its sphericity. The sphericity gives details of measuring shape character as compared to a sphere of the same volume. It may be helpful in determining the grain behavior of rolling and sliding and inter-granular pore spaces. Sphericity of chickpea grain was varying in the range of 0.78-0.81, IPC 4-98 variety showed the highest value of 0.81 ± 0.003 and lowest value for HC 5, and IPC 5-62 was observed with a value of 0.78 ± 0.006 . Eissa *et al.* (2010) reported it lying in the range of 0.85-0.87 for Giza 3 and Giza 195 cultivars which was slightly higher compared to the present result. Thus, the value obtained is used in determining the shape of the cell of the metering plate, while designing the planter. It was studied for gram (Dutta *et al.*, 1988) and pigeonpea (Shepherd and Bhardwaj, 1986) with respective values of 0.74 and 0.80. The sphericity was investigated as a function of moisture content for various pulses. The values were 0.840-0.815, 0.738-0.762, 0.806-0.816, 0.781-0.799 for greengram (Nimkar and Chattopadhyay, 2001), mothbean (Nimkar *et al.*, 2005), soybean grain (Deshpande *et al.*, 1993) and cowpea seeds (Yalcin, 2007), respectively. The variety with the sphericity near to one has higher rolling and easy to meter by the metering mechanism.

Mass and density

Thousand seed mass (TSM) is useful in estimating the required mass of seed in a given area by knowing the number of seeds from row-to-row and plant-to-plant spacing. The seed flow rate from the metering device to the tube varies with the seed mass. Bulk density (BD) is needed for deciding the volumetric capacity of the hopper to contain a sufficient quantity of seed and avoid repetitive filling. The true density (TD) along with bulk density and thousand seed mass is needed for selecting volume in constructing the hopper of the planter. The study revealed variations of TSM, BD and TD as 198-338 g, 830-880 kg m⁻³ and 1,310 and 1,350 kg m⁻³. TSM was highest for IPC 4-98 with 338 g and lowest for IPC 5-62 with 210 g. Bulk density was highest for IPC 4-98 with a value of 880 kg m⁻³ followed by DCP 92-3 (870 kg m⁻³) and lowest for JG 14 with a value of 830 kg m⁻³. In the case of true density, DCP 92-3 showed the highest value (1350 kg m⁻³), which may be due to smaller size of DCP 92-3, whereas, lowest (1310 kg m⁻³) for IPC 4-98, which may be due to bolder size of IPC 4-98. It was

found that varietal significant difference occurred in case of TSM, bulk density, and non-significant difference in case of true density of chickpea (Table 1). In past for different cultivars of chickpea under study, Eissa *et al.* (2010) reported values of 177-195 g, 694-730 kg m⁻³ and 1,225-1,308 kg m⁻³ for TSM, bulk density and true density. The same were 324 g, 570-536 kg m⁻³ and 1428-1368 kg m⁻³ respectively in different study for chickpea (Konak *et al.*, 2002). Thus, their values were 177-338 g, 570-880 kg m⁻³ and 1,225-1,428 kg m⁻³ respectively. Thousand seed mass was revealed as 173, 70, and 76 gram, respectively for gram (Dutta *et al.*, 1988), lentil seed (Carman, 1996) and pigeonpea (Shepherd and Bhardwaj, 1986), respectively. It was reported varying in the ranges of 138-173, 20.0-25.5, 39.46-51.13, 33.26-40.52, 110-127, 209-257 gram for gram (Islam *et al.*, 2001), lentil seed (Amin *et al.*, 2004), barley (Sologubik *et al.*, 2013), mothbean (Nimkar *et al.*, 2005), soybean grain (Deshpande *et al.*, 1993), cowpea seed (Yalcin, 2007), respectively. Bulk density was investigated for various pulses varying with moisture content. The grain studied were gram (Dutta *et al.*, 1988), greengram (Nimkar and Chattopadhyay, 2001), gram (Islam *et al.*, 2001), pigeonpea (Shepherd and Bhardwaj, 1986) and soybean grain (Deshpande *et al.*, 1993). Their respective values were 780-708, 807-708, 787.3-712.6, 832-768, 806-745, 735-708, 800-741 kg m⁻³ as reported by various researchers. However, lentil seed (Amin *et al.*, 2004) reported higher values of bulk density as 1190-935 kg m⁻³. The true density of gram (Dutta *et al.*, 1988), green gram (Nimkar and Chattopadhyay, 2001), gram (Islam *et al.*, 2001), lentil seed (Amin *et al.*, 2004), barley (Sologubik *et al.*, 2013) and pigeonpea (Shepherd and Bhardwaj, 1986) have also been studied. Their respective ranges were mentioned as 1311-1257, 1363-1292, 1398-1250, 1270-1212, 1220-1165, 1305-1251, and 1216-1124 kg m⁻³, respectively.

Coefficient of static friction (CSF)

The static friction coefficient of agricultural material is needed in selecting the material for the design and development of agricultural machinery. It varies with the surfaces against which the measurement is taken. Hopper in the planter needs material with the least value of the friction coefficient to have an optimum flow rate. The coefficient value for chickpea was obtained in the range of 0.370-0.560 with the least value for the surface of aluminium followed by galvanized iron and mild steel. On aluminium surface, CSF was observed in the range of 0.370 to 0.397, it was minimum for DCP 92-3 and

Table 2. Coefficient of static friction and angle of repose chickpea varieties

Variety	μ_s (Al)	μ_s (GI)	μ_s (MS)	θ (Degree)
JG-16	0.387±0.009	0.410±0.006	0.560±0.006	27.737± 0.333
HC-5	0.397±0.007	0.453±0.003	0.550±0.000	27.403± 0.333
KWR-108	0.383±0.007	0.443±0.007	0.547±0.009	27.403± 0.333
IPC-4-1	0.390±0.000	0.433±0.007	0.523±0.015	26.723 ±0.673
IPC-05-62	0.397±0.003	0.423±0.003	0.533±0.003	27.063± 0.583
DCP-92-3	0.370±0.000	0.443±0.007	0.557±0.003	27.730 ±0.660
IPC-04-98	0.390±0.000	0.420±0.000	0.520±0.006	26.390± 0.340
JG-14	0.390±0.000	0.410±0.006	0.537±0.017	27.063 ±0.583
Min	0.370	0.410	0.520	26.390
Max	0.397	0.453	0.560	27.737
F-value	2.70*	9.54*	3.28*	0.89**
CD (p=0.05)	0.014	0.016	0.027	N/A
SE(m)	0.005	0.005	0.009	0.502
SE(d)	0.007	0.007	0.013	0.710
CV	2.105	2.125	2.899	3.199

Note: μ_s =coefficient of static friction, Al=Aluminium, GI= Galvanized Iron, MS= Mild Steel, θ = angle of repose; * indicates 5% level of significance, and ** indicates not significant

highest for HC 5. On Galvanized Iron (GI) sheet, the value of CSF ranged from 0.410 (JG 14) to 0.453 (HC 5), whereas, on the Mild Steel (MS) sheet, the CSF value was observed highest for IPC 4-98 (0.520) and lowest for JG 14(0.560). There was significant difference in the CSF was observed for different varieties of chickpea on different surfaces (Table 2). Similarly, Eissa *et al.* (2010) reported the value of 0.321-0.741 for other cultivars of chickpea having lower values for stainless steel and galvanized iron surfaces. It was reported 0.384-0.651, 0.344-0.625 and 0.178-0.646 for gram (Dutta *et al.*, 1988), greengram (Nimkar and Chattopadhyay, 2001) and mothbean (Nimkar *et al.*, 2005) against various surfaces. Carman (1996) reported it as 0.374-0.532 for lentil seed, while studied against the surfaces of galvanized metal sheet, rubber and plywood. Shepherd and Bhardwaj (1986) found 0.26-0.37 as the same for pea against galvanized steel surface. Yalcin (2007) got these values in the ranges of 0.176-0.238, 0.212-0.296, 0.324-0.36 and 0.364-0.394, respectively, against the surfaces of stainless steel, aluminium, galvanized iron and rubber. Their maximum values were revealed against the surfaces of plywood for gram (Islam *et al.*, 2001) and concrete for lentil (Amin *et al.*, 2004). However, glass sheet was disclosed as the surfaces with the least friction (Islam *et al.*, 2001; Amin *et al.*, 2004)

Angle of repose

The repose angle is helpful in finding the minimum angle with which the material can flow freely through the hopper opening. It was found in the range of 26.4-27.7 degrees in the study. In the case of the angle of repose, there was a non-significant difference among the different varieties

of chickpea (Table 2.). In a different study, it was reported varying from 25.2 to 29.1 degrees for Giza 3 and Giza 195 cultivars of chickpea grains (Eissa *et al.*, 2010). However, the same was revealed as 25.2-29.1, while varying as a function of moisture content. Thus, the repose angle values directed the hopper angle to be kept exceeding the maximum value of the repose angle to ensure free flow of the grain. It was investigated as function of moisture content for gram (Dutta *et al.*, 1988), greengram (Nimkar and Chattopadhyay, 2001), gram (Islam *et al.*, 2001), barley (Sologubik *et al.*, 2013), pigeonpea (Shepherd and Bhardwaj, 1986) and mothbean (Nimkar *et al.*, 2005). Their respective values were varying in the ranges of 25.5-30.4, 26.6-31.0, 27.03-33.27, 18.18-27.31, 21.8-25.2 and 25.78-32.61 degree, respectively.

CONCLUSION

Chickpea grains of eight different cultivars were investigated for their physical and engineering properties useful for designing the planter. The capacity of the planter and its efficiency largely depends upon such properties varying with the cultivars. The properties include size, shape, mass, density, coefficient of friction, and angle of repose. The size and shape of the grain is helpful in determining the cell size and shape respectively. Based on this study, the size of the cell of the metering mechanism of the planter could be taken as 7-8, 8-9, and 9-10 mm by giving some clearances. Grain mass was used for estimating the mass of grains required for particular spacing of rows and plants. Mass and density were helpful in selecting the material for constructing the hopper sustaining the grain load. The coefficient of friction determined the roughness of surfaces against which the grains were to be slide

or roll. The hopper angle was taken higher than the maximum repose angle (27 degrees) to ensure free flow of the grain from the hopper opening.

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