Engineering properties of sorghum seeds: Implications for optimizing tractor-drawn multi-crop planter design

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Abstract: Optimal planter design requires understanding seed properties that impact seed-to-soil contact, metering, and planting uniformity. This study evaluates the engineering properties of three sorghum varieties (Dekeba, ESH-4, and Melkam) to optimize the design of a tractor-drawn multi-crop planter. Geometric properties (major, intermediate, minor diameters) of 100 seeds per variety were measured using digital calipers. Engineering properties (sphericity, flakiness ratio, aspect ratio, roundness) and gravimetric properties (bulk density, true density, porosity) parameters were analyzed via toluene displacement and statistical methods. Significant varietal differences were observed. ESH-4's optimal flow with an angle of repose of 33.1° and high sphericity of 80.66%, support compatibility with standard hopper designs. In contrast, Melkam, which has a lower angle of repose of 28.9° and high flakiness with a sphericity of 80.12 %, requires optimized hopper and metering systems to prevent bridging. Dekeba exhibited intermediate characteristics angle of repose of 32.38°, suggesting adaptability to various field conditions. The findings inform critical design parameters metering mechanisms adjusted for sphericity, optimized hopper geometries, and damage resistant materials to improve planting efficiency. This integration of seed properties with mechanized planting technology advances precision agriculture, reducing labor and supporting food security in semi-arid regions.

Keywords: Engineering properties, geometric parameters, gravimetric properties, multi-crop planter design, precision agriculture, sorghum seeds.

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1 Introduction

Sorghum (sorghum bicolor) is the most cultivated cereal globally and a cornerstone of African agriculture (IGAD, 2023), prized for its drought tolerance and remains a major producer, with Ethiopia emerging as a critical hub (Ministry of Agriculture, 2022). In 2022, Africa produced more than half the global total for sorghum, with Nigeria and Sudan together accounting for 21 percent of world volumes followed by the United States of America (8 percent of global production) (Lombardi, 2022). Sorghum's resilience underpins food security for over 20 million Ethiopians across drought-prone regions (Oromia,

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Amhara, Tigray, Somali), contributing 10 percent of national cereal output despite Ethiopia's persistent ranking among the ten worst food-insecure nations (CSA, 2023; IGAD, 2024). The country hosts diverse varieties like Dekeba, ESH-4, and Melkam, uniquely adapted to marginal soils and erratic climates (IGAD, 2023; Kapil, 2012; Zerssa et al., 2021).

Ethiopia's agricultural sector, contributing 34% of GDP and employing 71% of the population, however, adoption barriers include high costs, inadequate training, and machinery mismatched to smallholder needs, such as the prevalent medium horse power tractors (IGAD, 2024; Doldt et al., 2023; MoA, 2022; Wageningen University and Research, 2023). Despite its agro-economic significance, Ethiopian sorghum cultivation remains constrained by traditional practices such as manual broadcasting and oxen plowing, which result in poor seed spacing, uneven germination, and low yields (Gill et al., 2024). These inefficiencies are compounded by a lack of precision planting technologies tailored to local seed morphologies and soil conditions.

Current planting systems in Ethiopia are largely incompatible with the medium horsepower tractors commonly used by smallholder farmers (FAO, 2024; MoA, 2022). Existing tractor-drawn planters, often imported or designed for single crop, fail to accommodate Ethiopia's diverse agroecology, leading to suboptimal performance (Gaffney et al., 2020; MoA, 2022). A critical research gap persists in Ethiopian studies linking sorghum's engineering properties for geometric parameter optimization of existing planter to design the mechanical components fits the shape and sizes of sorghum varieties and planting spaces between seed to seed in row and row to row that could be compatible with the medium horse power tractor. For instance, mechanical seed meters like fluted rollers struggle with irregularly shaped seeds, causing damage and spacing inaccuracies (Sharma and Dewangan, 2023).

This study bridges a critical research gap by quantifying sorghum's geometric and gravimetric properties to systematically optimize the parameter for design of a multi-crop planter components like seed metering precision and flow dynamics, directly informing the development of hopper geometries and metering. By aligning planter components with seed traits, this work improves planting accuracy, reduces costs, and boosts yields, advancing sustainable agriculture and food security for smallholders in semi-arid Ethiopia.

2 Material and methods

2.1 Study location

The experiments were conducted at the Melkassa Agricultural Research Center (8°24'N, 39°12'E; 1,550 m asl) of Ethiopian Institute of Agricultural Research (EIAR) in East Shewa Zone, Oromia Region (CSA, 2023), as shown on Figure 1 described by ArcMap 10.8, approximately 107 km from Addis Ababa.

2.2 Sorghum varieties

Three widely cultivated and improved sorghum varieties were selected for this study Dekeba, ESH-4, and Melkam. These varieties were chosen based on their agronomic importance, adaptability to diverse agroecological conditions, and widespread adoption by smallholder farmers in Ethiopia. The selection of these varieties aligns with the study's objective of developing a multi-crop planter that accommodates the physical and engineering properties of Ethiopian relevant crops.

2.3 Determination of sorghum seed physical properties

The physical properties of sorghum seeds were analyzed to determine their engineering characteristics, which are critical for the design and optimization of a tractor-drawn multi-crop planter. The following parameters were measured using standardized methods and advanced instrumentation.

Seed dimensions: The length, width, and thickness diameters of 100 seeds from each variety were measured using a digital caliper with an accuracy of 0.01 mm. These measurements were used to calculate derived parameters such as the geometric mean diameter, sphericity, and aspect ratio, which are essential for understanding seed behavior and optimizing planter components.

2.4 Mathematical models for seed property analysis

The engineering properties of sorghum seeds were calculated using established mathematical models. These properties are critical for understanding seed behavior and optimizing the design of a tractor-drawn multi-crop planter. The following equations were used to determine the key parameters:

Arithmetic mean diameter, (D_a, mm) is a fundamental geometric parameter representing the average of the three principal linear dimensions of a seed: major (a, mm), intermediate (b, mm), and minor (c, mm) diameters. It is calculated using the Equation 1 (Kawuyo et al., 2022; Zewdie et al., 2024).

$$D_a = \frac{a+b+c}{3} \tag{1}$$

This parameter provides a simplified measure of seed size and is essential for designing seed metering mechanisms, hoppers, and other planter components to ensure compatibility with diverse seed dimensions.

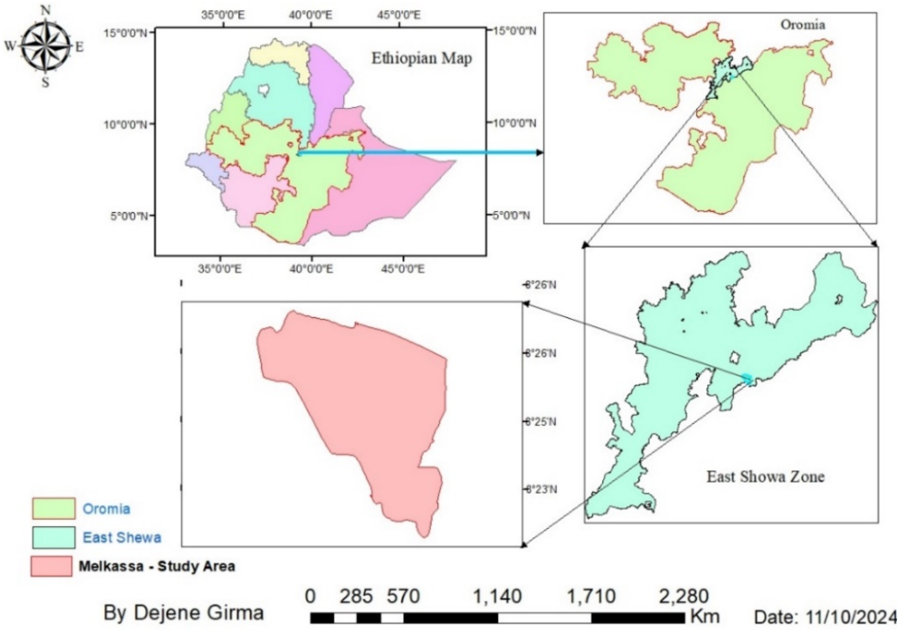

Figure 1 Experimental site

Geometric mean diameter, (D_g, mm) is a representative measure of seed size, calculated as the cube root of the product of the three principal linear dimensions: major (a, mm), intermediate (b, mm), and minor (c, mm) diameters (Panwar et al., 2023b; Soyoye et al., 2018) as stated on the Equation 2, useful for characterizing irregularly shaped seeds and plays a critical role in optimizing seed flow, spacing, and interaction with planter components such as seed tubes and metering mechanisms.

$$D_g = (a * b * c)^{\frac{1}{3}} \tag{2}$$

Square mean diameter, (D_s, mm) is a geometric measure used to approximate the effective size of an irregularly shaped of sorghum seed sizes (Biniam et al., 2024) as illustrated on the Equation 3:

$$D_s = (a * b + a * c + b * c)^{\frac{1}{3}} \tag{3}$$

Where: a is the longest intercept, b is the longest intercept normal to a, c is the longest intercept normal to a and b.

Projected area, (A_p, mm) is the two-dimensional area of a seed as seen from a specific angle, typically used to analyze how a seed appears in a plane (Kara et al., 2013; Zewdie et al., 2024) as stated on Equation 4:

$$A_p = \frac{\pi}{4} a * b \tag{4}$$

Surface area, ($\mathrm{A_s}$, $\mathrm{mm^2}$) the total area covering the outer surface of the sorghum. It is often approximated using an equivalent diameter (D_g), which represents the seed's characteristic dimension (Saparita et al., 2019; Zewdie et al., 2024) as stated on the Equation 5:

$$A_s = \pi * {D_g}^2 \tag{5}$$

Transverse surface area, ($\mathrm{A_t}$, $\mathrm{mm^2}$) represents the sorghum seed's cross-section perpendicular to its major axis as expressed on the following (Kara et al., 2013; Zewdie et al., 2024) as stated on Equation 6:

$$A_t = \frac{\pi}{4} b * c \tag{6}$$

Cross-sectional area, (A_{cs}, mm^2) is the surface exposed when the sorghum seed is sliced along a specific plane, (Kara et al., 2013; Zewdie et al., 2024) often expressed on Equation 7:

$$A_{cs} = \frac{\pi}{4}(a * c) \tag{7}$$

Sphericity, (Φ, %) indicates how closely the shape of a seed resembles a sphere. It is expressed as a percentage, with a perfect sphere having a sphericity of 100% (Panwar et al., 2023b; Zewdie et al., 2024) as it expressed in Equation 8:

$$\Phi = \frac{(a * b * c)^{\frac{1}{3}}}{a} = \frac{D_g}{a} \tag{8}$$

Flakiness ratio (F_r):

$$F_r = \frac{c}{b} * 100 \tag{9}$$

Aspect ratio (A_r)

$$A_r = \frac{b}{c} * 100 \tag{10}$$

Shape index (S_I) provides an indication of the relative proportions of the seed's dimensions and is useful in analyzing shape irregularities, (Zewdie et al., 2024) Equation 11:

$$S_I = \frac{a}{\sqrt{b * c}} \tag{11}$$

Roundness (R) is a dimensionless parameter that quantifies how closely the two-dimensional profile of a seed approximates a perfect circle, as shown on Equation 12 below (Zewdie et al., 2024). For sorghum seeds, roundness influences seed flow, orientation, and mechanical damage during planting, making it a critical parameter for optimizing the design of seed metering mechanisms, hoppers, and seed tubes in multi-crop planters (Panwar et al., 2023a; Zewdie et al., 2024).

$$R = \frac{4 * A_p}{\pi a^2} \tag{12}$$

Where; A_p is the projected area of the seed (mm^2) and a is the major diameter (mm).

2.5 Determination of angle of repose

The angle of repose for sorghum seeds was determined using a funnel setup, where seeds flowed freely onto a closed container to form a conical heap, following methodologies validated in seed flow studies (Mi et al., 2022; Kawuyo et al., 2022; Surpam et al., 2019).

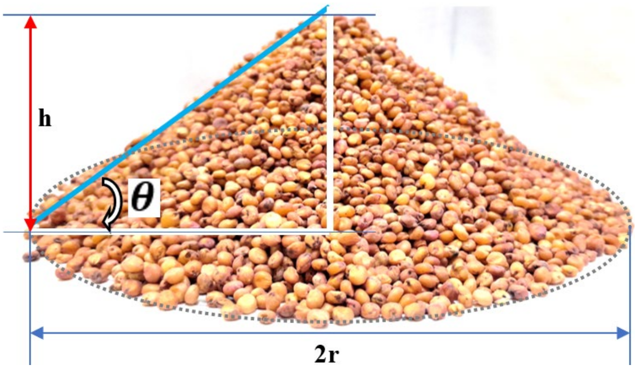

Figure 2 Measuring angle of repose of sorghum varieties

The apex height, (*h,* mm) and the base radius, (*r,* mm) of the formed cone was measured to calculate the angle of repose (θ,°). Using the trigonometric relationship, the angle of repose was computed as

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \tag{13}$$

2.6 Determination of the gravimetric parameters

The gravimetric properties of selected sorghum varieties (Dekeba, ESH-4, and Melkam) were evaluated to optimize planter design. True density and seed volume were measured using toluene displacement to prevent water absorption. Bulk density, porosity, and density ratio were derived from the relationship between seed weight and volume, while thousand seed mass was also calculated as stated on Equation 14 - 18 (Biniam et al., 2024):

True density ρ_t, kgm^{-3},

$$\rho_t = \frac{Weight\ of\ the\ sorghum\ sample\ (g)}{Volume\ of\ Toluene\ displced\ (cm^3)} \tag{14}$$

Bulk density ρ_b, kgm^{-3},

$$\rho_b = \frac{Weight\ of\ the\ sorghum\ sample\ (g)}{Volume\ of\ occupied\ (cm^3)} \tag{15}$$

Porosity ε, %

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) * 100\ \% \tag{16}$$

Density ratio R_ρ, %

$$R_\rho = \frac{\rho_b}{\rho_t} * 100\ \% \tag{17}$$

Thousand seed mass T_{sm} , g

$$T_{sm} = \frac{\sum_i^n weight\ of\ sorghum\ samples\ \ (g)}{n}, \quad i = 1, 2, 3 \ldots \tag{18}$$

2.7 Statistical analysis

Statistical analysis (ANOVA, $P < 0.05$) was conducted using Minitab to compute descriptive statistics (means, standard deviations, variance) for optimizing the multi-crop planter's design parameters and components.

3 Results and discussion

The analysis of dimensional parameters in Table 1 reveals distinct morphological differences among sorghum varieties. ESH-4 exhibited the largest seeds, with the highest major diameter (4.486 ± 0.231 mm) and geometric mean diameter (3.615 ± 0.171 mm), while Melkam showed the highest minor diameter (2.652 ± 0.185 mm), indicating thicker seeds. Elongation ratios further highlighted variability: Melkam displayed the greatest elongation at the width orientation (1.163 ± 0.063), whereas ESH-4 had the highest elongation at the thickness orientation (1.786 ± 0.144). These findings align with recent studies emphasizing the role of seed geometry in mechanized planting. For instance, Kawuyo et al. (2022), and Sinha et al. (2021) demonstrated that larger seed dimensions, such as those of ESH-4, necessitate calibrated seed-metering systems to prevent planting inefficiencies like seed bounce or clogging. Similarly, (Biniam et al., 2024; Mahapatra et al., 2024) linked elongation ratios to seed orientation dynamics in planter trays, corroborating the need for equipment adjustments to accommodate Melkam’s flatter morphology.

Table 2 highlights surface area and shape-related traits, with ESH-4 again showing the largest mean surface area (41.147 ± 3.856 mm²) and projected area (14.749 ± 1.287 mm²), reflecting its greater exposure during planting. Dekeba’s high sphericity (85.467% ± 2.867%) and roundness (1.029 ± 0.040) contrast sharply with Melkam’s flakiness ratio (69.392% ± 4.294%) and lower aspect ratio (144.66% ± 9.06%), as shown in Figure 3.

Conversely, Hadebe (2020) identified flakiness ratios > 65% as a risk factor for seed bridging in hoppers, aligning with challenges posed by Melkam’s morphology. Conversely, Hadebe (2020) identified flakiness ratios > 65% as a risk factor for seed bridging in hoppers, aligning with challenges posed by Melkam’s morphology. Recent work by Surpam et al. (2019) further emphasized that surface area and cross-sectional metrics directly influence aerodynamic behavior during seed release, necessitating adjustments in hopper angles and metering mechanisms for larger seeds like ESH-4, note in Table 1 and Table 2. The coefficient of variation for sphericity (3.35% - 4.05%) underscores moderate intra-varietal variability, consistent with Sardar Baig et al. (2019), who noted that shape standardization methods like elliptic Fourier analysis are critical for capturing such morphological diversity in sorghum.

The analysis of key physical properties among three sorghum varieties (Dekeba, ESH-4, Melkam) in Table 3 reveals distinct varietal characteristics critical for optimizing agricultural equipment design. Melkam’s superior thousand seed mass (32.597 g) and true density (1278.050 kgm⁻³), consistent with studies linking high grain density to structural integrity (Nurgi et al., 2023) suggest enhanced mechanical handling and compactness, whereas ESH-4’s lower bulk density (761.763 kgm⁻³) and elevated porosity (39.641%). These traits influence seed flow dynamics and packing efficiency, as evidenced by the mean density ratio

(0.620 ± 0.014), which correlates with optimal thresholds for minimizing mechanical damage (Mahapatra et al., 2024).

The findings underscore the necessity of varietal-specific adjustments in planter design, such as reinforced metering systems for heavier seeds like Melkam and modified hoppers for ESH-4 to mitigate clogging, reflecting broader agricultural imperatives to align equipment with physicochemical diversity (Julia, 2023). By integrating these insights, future designs can enhance planting precision, storage efficiency, and adaptability to sorghum’s biomechanical variability, ultimately advancing sustainable crop management practices.

Table 1 ANOVA values physical properties of sorghum varieties

Parameters	SV	Mean	StDev	V	CV	Min	Max	Mean ± StDev
a (mm)	Dekeba	4.073	0.2	0.04	4.9	3.63	4.55	4.073 ± 0.2
	ESH-4	4.486	0.231	0.054	5.16	3.94	5.15	4.486 ± 0.231
	Melkam	4.443	0.219	0.048	4.94	3.97	4.92	4.443 ± 0.219
b (mm)	Dekeba	4.033	0.22	0.049	5.46	3.55	4.47	4.033 ± 0.22
	ESH-4	4.181	0.208	0.043	4.98	3.68	4.63	4.181 ± 0.208
	Melkam	3.825	0.198	0.039	5.17	3.35	4.37	3.825 ± 0.198
c (mm)	Dekeba	2.569	0.195	0.038	7.6	1.95	2.98	2.569 ± 0.195
	ESH-4	2.525	0.195	0.038	7.73	2.02	2.95	2.525 ± 0.195
	Melkam	2.652	0.185	0.034	6.99	2.21	3.07	2.652 ± 0.185
Ew	Dekeba	1.011	0.049	0.002	4.850	0.898	1.159	1.011 ± 0.049
	ESH-4	1.074	0.054	0.003	5.060	0.932	1.193	1.074 ± 0.054
	Melkam	1.163	0.063	0.004	5.440	1.002	1.364	1.163 ± 0.063
Et	Dekeba	1.592	0.112	0.013	7.030	1.321	1.923	1.592 ± 0.112
	ESH-4	1.786	0.144	0.021	8.060	1.354	2.095	1.786 ± 0.144
	Melkam	1.682	0.125	0.016	7.450	1.421	2.039	1.682 ± 0.125
El	Dekeba	1.576	0.103	0.011	6.540	1.286	1.892	1.576 ± 0.103
	ESH-4	1.662	0.106	0.011	6.380	1.378	1.965	1.662 ± 0.106
	Melkam	1.447	0.091	0.008	6.260	1.233	1.692	1.447 ± 0.091
Dg (mm)	Dekeba	3.48	0.173	0.03	4.98	2.961	3.842	3.48 ± 0.173
	ESH-4	3.615	0.171	0.029	4.73	3.15	4.022	3.615 ± 0.171
	Melkam	3.557	0.159	0.025	4.46	3.133	3.866	3.557 ± 0.159
Da (mm)	Dekeba	3.559	0.17	0.029	4.78	3.083	3.923	3.559 ± 0.17
	ESH-4	3.73	0.167	0.028	4.48	3.277	4.15	3.73 ± 0.167
	Melkam	3.64	0.156	0.024	4.29	3.227	3.94	3.64 ± 0.156

Note: a= Major diameter, b= Intermediate diameter, c= Minor diameter, Ew= Elongation at the width, Et= Elongation at the thickness, El= Elongation at the thickness, Dg= Geometric diameter, Da= Arithmetic diameter, StDev = Standard deviation; CV = Coefficient of variation, SV= Sorghum varieties, V=Variance, ESH-4= Ethiopian sorghum hybrid 4th

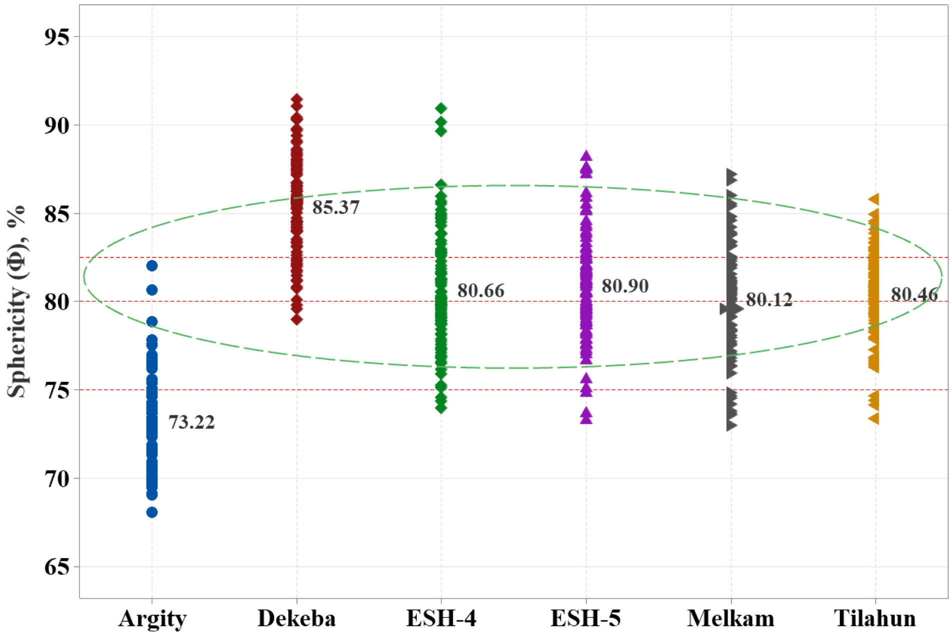

Figure 3 Sorghum seed varieties (sphericity of Dekeba, ESH-4, and Melkam) mean values

Table 2 ANOVA values physical properties of selected sorghum varieties

Parameters	SV	Mean	StDev	V	CV	Min	Max	Mean ± StDev
As (mm²)	Dekeba	38.128	3.766	14.186	9.88	27.543	46.362	38.128 ± 3.766
	ESH-4	41.147	3.856	14.867	9.37	31.179	50.821	41.147 ± 3.856
	Melkam	39.815	3.499	12.244	8.79	30.828	46.947	39.815 ± 3.499
Ap (mm²)	Dekeba	12.922	1.185	1.405	9.17	10.456	15.693	12.922 ± 1.185
	ESH-4	14.749	1.287	1.657	8.73	11.75	18.121	14.749 ± 1.287
	Melkam	13.362	1.133	1.283	8.48	10.778	15.776	13.362 ± 1.133
Ats (mm²)	Dekeba	8.156	0.931	0.867	11.41	5.437	9.961	8.156 ± 0.931
	ESH-4	8.307	0.929	0.862	11.18	6.139	10.247	8.307 ± 0.929
	Melkam	7.983	0.835	0.698	10.46	5.92	9.757	7.983 ± 0.835
Acs (mm²)	Dekeba	29.903	2.838	8.054	9.49	22.4	36.268	29.903 ± 2.838
	ESH-4	32.854	2.921	8.53	8.89	25.297	40.58	32.854 ± 2.921
	Melkam	31.278	2.647	7.008	8.46	24.531	36.577	31.278 ± 2.647
Fr (%)	Dekeba	63.737	4.146	17.192	6.51	52.857	77.748	63.737 ± 4.146
	ESH-4	60.408	3.963	15.704	6.56	50.882	72.569	60.408 ± 3.963
	Melkam	69.392	4.294	18.441	6.19	59.091	81.081	69.392 ± 4.294
Ar (%)	Dekeba	157.55	10.31	106.22	6.54	128.62	189.19	157.55 ± 10.31
	ESH-4	166.23	10.61	112.58	6.38	137.8	196.53	166.23 ± 10.61
	Melkam	144.66	9.06	82.14	6.26	123.33	169.23	144.66 ± 9.06
Si (%)	Dekeba	1.268	0.064	0.004	5.05	1.134	1.425	1.268 ± 0.064
	ESH-4	1.384	0.082	0.007	5.95	1.153	1.572	1.384 ± 0.082
	Melkam	1.398	0.08	0.006	5.71	1.229	1.605	1.398 ± 0.08
R	Dekeba	1.029	0.04	0.002	3.86	0.949	1.14	1.029 ± 0.04
	ESH-4	1.053	0.035	0.001	3.3	0.981	1.159	1.053 ± 0.035
	Melkam	0.969	0.035	0.001	3.59	0.863	1.087	0.969 ± 0.035

Note: A_s= Surface area, A_p= Projected area, A_{ts}= Transverse surface area, A_{cs}= Cross-sectional area, F_r= Flakiness ratio, A_r= Aspect ratio, S_i= Shape index, R= Roundness, StDev = Standard deviation; CV = Coefficient of variation, SV= Sorghum varieties, V=Variance, ESH-4= Ethiopian sorghum hybrid 4th

Table 3 Statistical description of gravimetric properties of selected sorghum varieties

Parameters	TSM	True density	Bulk Density	Porosity	Density Ratio
Dekeba	27.503	1246.650	780.951	37.356	0.626
ESH-4	31.123	1262.050	761.763	39.641	0.604
Melkam	32.597	1278.050	803.387	37.140	0.629
Mean	30.408	1262.250	782.034	38.046	0.620
StDev	2.621	15.701	20.833	1.386	0.014
Variance	6.870	246.520	434.018	1.921	0.0002
CV	8.620	1.240	2.660	3.640	2.240
Minimum	27.503	1246.650	761.763	37.140	0.604
Maximum	32.597	1278.050	803.387	39.641	0.629
Mean ± StDev	30.408±2.621	1262.25±15.701	782.034±20.833	38.046±1.386	0.62±0.014

Note: StDev = Standard deviation; CV = Coefficient of variation, ESH-4= Ethiopian sorghum hybrid 4th, TSM=Thousands of seed mass

Table 4 ANOVA values angle of repose of selected sorghum varieties

Parameters	Mean	StDev	Variance	CV	Minimum	Maximum	Mean ± StDev
Dekeba	32.383	1.586	2.515	4.900	29.956	33.887	32.383 ± 1.586
ESH -4	33.070	0.765	0.585	2.310	32.246	33.756	33.07 ± 0.765
Melkam	28.945	2.197	4.826	7.590	27.054	31.355	28.945 ± 2.197

Note: StDev = Standard deviation; CV = Coefficient of variation, ESH-4= Ethiopian sorghum hybrid 4th

The recent studies highlight the importance of varietal-specific adjustments in planter design to optimize seed placement efficiency (Bhiman et al., 2019; Anand et al., 2024). The angles of repose for Dekeba (32.38° ±1.59°), ESH-4 (33.07° ±0.76°), and Melkam (28.95° ±2.20°) reveal distinct flow properties as illustrated in Table 4. ESH-4 exhibits the highest mean angle with minimal variability 2.31%, indicating stable flow suitable for fixed hopper geometries (Biniam et al., 2024; Shah et al., 2022; Soyoye et al., 2018). In contrast, Melkam's lower angle and higher variability 7.59% suggest irregular flow, likely due to its drought-adaptive panicle morphology, necessitating dynamic calibration. Dekeba's moderate values 4.90% balance predictability and adaptability, aligning with its agronomic versatility. These findings underscore the need for tailored adjustments, such as optimized hopper designs for ESH-4 and flexible metering systems for Melkam, to enhance seed placement efficiency.

4 Conclusion

The study revealed significant varietal differences in the geometric and gravimetric properties of sorghum seeds, underscoring the need for optimized planter component design. Critical seed parameters including length, width, thickness, elongation, geometric mean diameter, cross-sectional area, roundness, and sphericity were found to directly influence the configuration of key components such as the hopper, metering mechanism, and seed tube in multi-crop planters. High-sphericity seeds; Dekeba, with 85.37% sphericity and a 32.38° angle of repose, exhibit superior flowability, enabling efficient operation in gravity-fed systems with minimal mechanical assistance. Conversely, irregularly shaped seeds like Melkam and ESH-4, with 80.12% and 80.66% sphericity alongside repose angles of 28.95° and 33.07° respectively, necessitate dynamic calibration to prevent seed bridging and ensure consistent delivery.

Roundness measurements indicated ESH-4 as the roundest with 1.05 and a coefficient of variation of 3.30%. Hence, the sorghum varieties are small-seeded crops; require precision mechanisms including narrow metering orifices and adjustable baffles for accurate delivery.

ESH-4's surface area (41.147mm^2) facilitate smooth flow, in contrast, Melkam demonstrated the greatest uniformity with lower coefficients of variation ranging from 4.46% to 4.61%. Integrating sorghum seed morphology with planter design enhances seed metering, hopper efficiency, and flow dynamics, supporting precision planting and improved productivity for smallholder farmers in semi-arid regions. Future research should focus on design optimizations and extend these insights to other crops, further improving agricultural sustainability and productivity.

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