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Application of the physical properties of local cowpea varieties in the development of a multi-variety cowpea cleaner

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Abstract: Cowpea, an annual legume widely grown and consumed in Nigeria, has been observed to contain between 27–33% impurities when freshly harvested and threshed. This poses a threat to humans when consumed and in large-scale agricultural processing. Therefore, this study is aimed at developing and evaluating the performance of a multi-variety cowpea cleaner (MVCC). Using standard methods, some selected engineering properties of the cowpea varieties were examined and used in the design of the MVCC. The cowpea had a moisture content of 8–14%, depending on the locations and varieties. Other properties investigated include the length, width, thickness, sphericity, geometric mean diameter, unit volume, arithmetic mean diameter, aspect ratio, surface area, unit weight, true density, terminal velocity, and angle of repose. The MVCC comprised the hopper, winnower, cleaning unit, fan assembly, and frame. The performance of the MVCC was also evaluated. The efficiency of separating good products of honey, drum, and Sokoto White beans was 95, 91, and 84%, respectively, while separating bad products was 87, 94, and 96%, respectively.

Keywords: cleaning; drum beans; honey beans; separation; Sokoto white beans; quality of cleaning

Production of cowpea on a large scale has increased with the adoption of improved production technology and the availability of a wider market. This means a higher demand for labour in all farming operations particularly harvesting, threshing, cleaning, and grading (Irtwange 2009). It should also be noted that a freshly harvested cowpea grain contains between 27–33% impurities, posing a threat to human consumption and large-scale agricultural processing. There is now a general understanding in Nigeria and other developing countries that efficient deployment of modern agricultural technology is crucial to fast agricultural expansion. Contaminants were removed from seeds by hand before introducing the first set of machines (Olajide et al. 2022). The manual process is usually time and energy-consuming and the separation efficiency is low. This led to the invention of cleaning machines.

The operation of these machines consists almost solely of aspirators and sieves for separating non-edible impurities such as rubble, lumps, sticks, straw, string, and trapped irons, which are liable to cause regular problems and are dangerous to livestock (Orobinsky et al. 2022). The already cleaned grains are then separated into sizes through a process known as sorting. A specific case of sorting is size grading. This is the separation of grain with specific dimensions from the basic material. The separation process uses differentiating characteristics of seeds (Kim et al. 2022). This sorting is achieved by using

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a precise machine equipped with devices for the feeding and metering of the input material and the separate fraction collection (Shevchenko and Aliiev 2022). This can be operated either pneumatically or by an aspirator. The common and basic methods employed in the cleaning of agricultural products include the following: washing, hand picking, screening, and air (or pneumatic) separation (Kaur et al. 2022).

Clean grain has a higher value than grain contaminated with straws, chaff, weed seeds, soil, rubbish, and other non-grain materials. Grain cleaning improves grain drying and storability, reduces dockage (or docking fee) at the time of milling, and improves milling output and quality (Nunes et al. 2022). Seed cleaning reduces disease damage and improves yields. Examples of cleaning operations include removing shattered pods from cowpea and stones and pebbles from whole grains (Zhu et al. 2022).

When the cowpea is properly cleaned after threshing by removing the chaff, dehulling the cowpea is easier and faster (Babalola et al. 2023). Cleaning and screening not only give the grains a fresh and clean look by blowing away and removing most impurities but also greatly enhance the efficiencies of grains processed by on-farm crushing machines before consumption by the herd. Cleaning is an important post-harvest operation that is aimed at removing impurities or contaminants from harvested grains. It is indispensable before drying, storage, marketing, or further processing of the products takes place. Clean and homogenous grains attract a high premium for sales, resulting in high profits for farmers. Several researchers have developed different cleaning machines for different grains, such as air-screen cleaners for beniseed (Akinoso et al. 2010), continuous flow cowpea cleaners (Aguirre and Garay 1999), reciprocating screen cereal cleaners (Okunola and Igbeka 2009), rotary screen cleaner for cowpea (Aderinlewo et al. 2016). Most of these researchers reported that the performance of these machines is influenced by factors such as air velocity, injection angle, amplitude, and frequency of oscillation of sieves. One major factor that affects the performance of cleaning machines is the properties of the product to be cleaned, while the moisture content and the size affect other properties (Sadiku et al. 2021; Nwakuba et al. 2022). These properties are used to design machines for cleaning and other post-harvest operations (Parniakov et al. 2022; Sudaryanto et al. 2022).

Several researches have been conducted on various properties of cowpea. Faleye et al. (2013) investigated the engineering properties of cowpea grains, including the physical and mechanical properties of some cowpea varieties, while Kabas et al. (2007) established the physical and nutritional properties of cowpea seeds (*Vigna sinensis* L.). The engineering properties of cowpeas (*Vigna unguiculata*) related to the design of processing machines were carried out by Chukwu and Sunmonu (2010). Although these researches showed the significance of the cowpea properties, their applications were limited. Cowpea still has high impurities compared to Parniakovet et. al. (2022) other grains sold in markets (Anugwomet et.al. 2021). Stones, chaff, weevils, and insect-damaged cowpeas are some of the impurities still present in the cowpea sold in the market. Therefore, there is a need for a machine that will ensure the quality of the marketed cowpea. This study is aimed at developing a multi-variety cowpea cleaner (MVCC) for markets in southwestern Nigeria to proffer a solution to the problem of high levels of impurities present in cowpea. It was observed that no cleaner has been designed to effectively clean three varieties which this machine has been able to achieve.

MATERIAL AND METHODS

Determining the physical properties of cowpea varieties

Moisture content. In each of the three tarred moisture dishes, 15 g of each Cowpea variety was inserted. The plates were then placed in the oven and uncovered. The oven was preheated to 103 °C for 72 hours. The dishes were quickly covered and placed in a desiccator when the drying was over. When the dishes had reached room temperature, they were weighed. The percentage of moisture (wet basis) was calculated by dividing the weight loss due to heating by the original sample weight and multiplying by 100. (Equation 1). Three replicates were performed. (ASAE 1998).

$$\text{Moisture content}\,(\%) = \frac{w_1 - w_2}{w_1 - w_0} \times 100 \tag{1}$$

where: W_0 – weight of dish (kg); W_1 – weight of dish + sample before drying (kg); W_2 – weight of dish + sample after drying (kg).

Size. The fundamental dimensions of the seed (major, minor, and intermediate diameters) were meas-

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ured using a digital micrometre with an accuracy of 0.001 mm on 200 grains at random. The arithmetic and geometric average diameters of cowpea for each variety were computed using Equations 2 and 3.

$$AMD = \frac{L + W + T}{3} \quad (2)$$

$$GMD = (LWT)^{1/3} \quad (3)$$

where: AMD – arithmetic mean diameter (mm); GMD – geometric mean diameter (mm); L – length (mm); W – width (mm); T – thickness (mm).

Units weight, volume, true density, and angle of repose. In line with Arije et al. (2019) and Adetifa et al. (2023), the unit weight was determined using a weighing scale, and the unit volume was calculated using Equation 4. The true density was estimated as a ratio of the unit weight to unit volume (Equation 5). Equation 6 was used to estimate the angle of repose of the three cowpea varieties.

$$\text{Volume} = \frac{LWT}{6} \quad (4)$$

$$\text{True density} = \frac{\text{weight}}{\text{volume}} \quad (5)$$

$$\theta = \frac{\tan^{-1} 2H}{3(d\rho)} \quad (6)$$

where: H – the height of the material (cm); d – the diameter of the material (cm).

Terminal velocity. The terminal velocity was estimated using Equation 7 as reported by Fellows (2000):

$$V_e = \frac{4d \times (\rho_s - \rho)}{3(d\rho)} \quad (7)$$

where: v_e – terminal velocity; ρ_s – density of the material; d – geometric mean diameter of the material; – air density (1.2 kg·m^{-3}).

Surface area, aspect ratio, and sphericity. Equation 8 determined the surface area, while Equation 9 obtained the aspect ratio. Equation 10 determined the sphericity.

$$\text{Surface area} = \pi(\text{GMD})^2 \quad (8)$$

$$\text{Aspect ratio} = \frac{W}{L} \quad (9)$$

$$\text{Sphericity} = \frac{(LWT)^{1/3}}{L} \quad (10)$$

Machine description and operation

The MVCC (Figure 1) comprises the following components: hopper, winnower, cleaning unit, grading/separation sieves, delivery chutes, fan assembly, and frame. During operation, the material is fed into the cleaning chamber via the hopper constructed of mild steel metal sheet (gauge 18). Winnowing and cleaning (grain/chaff separation) occur within the cleaning chamber. The fan was centrifugal in design, with three straight blades aligned at 120 ° around the shaft. The threshed grains passed through the screen, while the chaffs were transported to the axial end of the threshing chamber and discharged through the chaff outlet. Clean grains were gathered by the outlet, while lighter particles were blasted away by the fan assembly.

Design considerations

The MVCC was designed taking cognisance of cowpea grains and chaffs' differences in aerodynamic properties. The physical properties of the grains and impurities were also considered in screen selection. This machine consists of a hopper sitting directly above an air duct, beneath which is a channel connected to the screen. The screen was inclined at an angle of 30 ° to have gravity aid for grain flow across the screen.

The design process

The equations used were adapted from Ndirika and Onwualu (2016).

The hopper. The characteristics of the material dictate the configuration of the hopper. The hopper's depth and the gate height were designed using the true density and the angle of repose (Equations 11 and 12), respectively.

Figure 1. Multi-variety cowpea cleaner

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$$d = \frac{4800 \times C}{\left[(w-4)RD\right]} \quad (11)$$

$$H = \mathrm{GF} \times d \quad (12)$$

where: W – the feeder width (m); C – the capacity (kg·s^{-1}); d – the discharge depth (m); GF – the gate factor (for material with an angle of repose < 35 °, GF = 1.3, while *if* > 35 °, GF = 1.5); D – the material density (kg·m^{-3}); H – the gate height (m); R – the flow rate (m·min^{-1}).

For a capacity of 0.4 t·hr^{-1}, a standardised feeder width and flow rate of 9.5 m and 22.56 m·min^{-1}, respectively, the estimated discharge depth was 1.17 m, and the gate height was 1.50 m. The density and angle of repose used were obtained from the physical properties measured.

Determination of shaft diameter based on strength. Design of shafts of ductile materials based on·strength is controlled by maximum shear theory. For a solid shaft having little or no axial loading, the ASME code equation was used (Equation 13).

$$d_s^3 = \left(\frac{16}{\pi S_s}\right) \times \left[\left(K_b \times M_b\right)^2 + \left(K_t \times M_t\right)^2\right]^{1/2} \quad (13)$$

where: d_s – diameter of the shaft; M_t – torsional moment (42 × 10^3 N·mm^{-1}); M_b – bending moment (24.72 × 10^3 N·mm^{-1}); K_b – combined shock and fatigue factor applied to bending moment; 2.0 for minor shock; K_t –combined shock and fatigue factor applied to torsional moment (1.5 for minor shock); S_s – allowable stress (40 MN·m^{-2} for shaft with keyway).

Therefore, a shaft of 25 mm is selected to bear the bending and twist load of the machine.

Determination of fan speed. The fan's speed was determined using the terminal velocity of the material evaluated with SPSS (software version 20). The 5th percentile of the result obtained, which is 5.37 m·s^{-1} was used for the fan's speed.

Screen characteristics. When solid particles are dropped over a screen, particles smaller than the screen size pass through it; therefore, larger particles are retained on the screen.

The critical speed of rotation. According to Igbeka (2013), the critical rotation speed occurs when the centrifugal force is equal to the gravitational force. It was determined using Equation 14. For a radius of eccentricity, the critical speed of rotation of the screen was estimated to be 36.27 revolutions per minute (rpm).

$$N_c = \left(\frac{60}{2\pi}\right)\left(\frac{g}{R}\right)^{\frac{1}{2}} \quad (14)$$

where: g – the acceleration due to gravity (m·s^{-2}); R – the radius of eccentricity (m); N_c – the critical speed (rpm).

Screen holes. The geometric mean diameter of the cowpea was used to characterise the width of the screen opening. The MVCC was designed to have three concentric screens; hence, the 5th, 50th and 95th percentile of the geometric mean diameter of the cowpea samples were selected for the width of the screen opening D of the small, medium, and largest screen, respectively. The open area of the circular screen was determined using Equation 15 (Igbeka 2013). For efficient screening, the effective opening, O_E, is usually 40%; hence the distance between the elongated sides of the opening d_o was estimated for each screen size.

$$O_E = \left(\frac{open\,area}{total\,area}\right) = \frac{D^2}{\left(D + d_0\right)^2} \quad (15)$$

where: D – the width of the opening (mm); d_0 – the distance between the elongated sides of the opening.

The fabrication process of multi-variety cowpea cleaner

Figure 2 shows the fabrication process of the MVCC, which comprises drilling the sieves, fixing sieves on the rotor, fabricating the hopper and the cross-section plastic cylinder, attaching the hopper with a cross-section plastic cylinder on the frame, assembling the sieve on the frame; painting and covering with a cylinder the sieves on the frame.

Performance evaluation

Quality of cleaning. The quality of separation of the MVCC was evaluated based on the flowchart in Figure 3. Cowpea samples (200 g) and dirt (50 g) were mixed into the machine to clean.

The efficiencies of separating good product, E_G, bad reject E_B, and total efficiency were estimated using Equations 16, 17, and 18, respectively.

$$O_G = \left(\frac{G \times P}{G \times P + G \times R}\right) \quad (16)$$

$$E_B = \left(\frac{B \times R}{B \times R + B \times P}\right) \quad (17)$$

$$E_T = E_G \times E_B \quad (18)$$

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where: G_R – the good reject (g); B_R – the bad reject (g) G_P – the good product (g); B_P – the bad product (g); E_G – the efficiency of good (%); E_B – the efficiency of bad (%); E_T – the total efficiency (%).

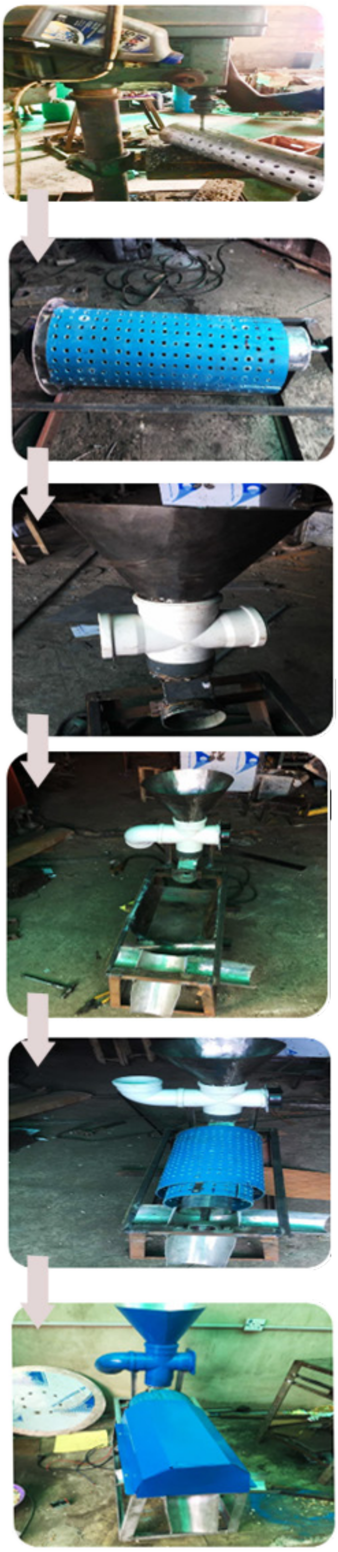

Figure 2. The fabrication process of multi-variety cowpea cleaner

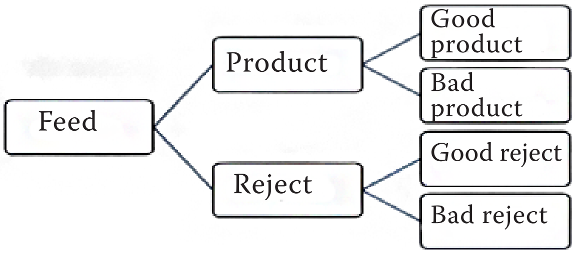

Figure 3. Quality of separation
Source: Igbeka 2013

RESULTS AND DISCUSSION

Physical properties of selected varieties of cowpea. The moisture content of the cowpea varieties at each market is presented in Table 1. The honey, drum, and Sokoto white cowpea from the Ibogun market were 10.45, 9.33 and 8.22%, respectively, while that of the Ilaro market was 11.11, 8.00, and 14.00%, respectively.

Table 2 show the physical properties of the varieties collected from the two locations. The result of the analysis of variance (ANOVA) conducted on the samples is presented in Tables 3 and 4, respectively, showing the effect of the variety and location on individual properties. The length, width, and thickness of the varieties of honey beans from the Ibogun market are 0.99, 0.70, and 0.52 cm, respectively, while for Ilaro, the respective values are 1.01, 0.73, and 0.53 cm. For drum beans in Ibogun, the length, width, and thickness are 1.04, 0.96, and 0.88 cm, respectively, while for Ilaro, it is 1.17, 0.82, and 0.58 cm, respectively. For the Sokoto white cowpea from the Ibogun market, the length, width, and thickness were found to be 1.00, 0.95, and 0.90 cm, respectively, while for Ilaro, it is 1.04, 0.84, and 0.65 cm, respectively. The length, width, and thickness values were comparable to those of the chicken pea, cowpea and jamun (Syzgium cuminii) seeds, as determined by Adanu et al. (2022). For red and black cowpea, Hamid et al. (2016) findings were noticeably less significant. Grain dimensions are considered while choosing sieve apertures and other design factors for agricultural machinery (Mohsenin 1986).

Table 1. Moisture content of cowpea (dry basis, %)

Location	Variety		
	Honey	Drum	Sokoto white
Ibogun	10.45	9.33	8.22
Ilaro	11.11	8.00	14.00

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Table 2. Physical properties of cowpea from Ibogun market and from Ilaro market

Variety	Percentile	*L* (cm)	*W* (cm)	*T* (cm)	*SP*	*GMD* (cm)	*UV* (cm^3)	*AMD* (cm)	AR	*SA* (cm^2)	*UW* (g)	ρ ($g·cm^{-3}$)	*V* ($m·s^{-1}$)	θ (°)
Ibogun market														
Drum bean		1.04	0.96	0.88	0.73	0.86	0.11	0.73	0.73	2.31	2.83	12.17	0.31	31.13
	5^{th}%ile	1.00	0.73	0.53	0.66	0.74	0.07	0.66	0.62	1.73	1.62	8.26	0.20	29.82
	25^{th}%ile	1.00	0.94	0.68	0.69	0.82	0.09	0.71	0.67	2.13	2.01	10.50	0.25	30.07
	75^{th}%ile	1.03	1.00	1.00	0.76	0.89	0.12	0.76	0.76	2.51	3.44	14.03	0.40	32.00
	95^{th}%ile	1.24	1.00	1.00	0.79	0.95	0.14	0.80	0.84	2.85	4.34	15.12	0.45	33.02
	SD	0.09	0.08	0.19	0.04	0.06	0.02	0.05	0.07	0.30	0.86	2.13	0.09	1.18
Honey beans		0.99	0.70	0.52	0.72	0.71	0.06	0.74	0.72	1.59	0.18	2.95	6.92	32.94
	5^{th}%ile	0.85	0.62	0.46	0.67	0.64	0.04	0.66	0.63	1.30	0.10	1.42	4.90	30.24
	25^{th}%ile	0.92	0.71	0.48	0.69	0.69	0.06	0.72	0.68	1.51	0.10	1.77	5.33	31.22
	75^{th}%ile	1.02	0.72	0.56	0.74	0.74	0.07	0.76	0.72	1.71	0.20	3.65	7.76	34.31
	95^{th}%ile	1.12	0.76	0.58	0.79	0.77	0.08	0.80	0.86	1.86	0.30	5.13	9.35	36.87
	SD	0.08	0.05	0.05	0.04	0.04	0.01	0.04	0.07	0.16	0.07	1.20	1.49	1.95
Sokoto White		1.00	0.95	0.90	0.81	0.86	0.11	0.87	0.78	2.34	0.33	2.81	7.62	33.54
	5^{th}%ile	0.92	0.74	0.59	0.72	0.76	0.07	0.77	0.67	1.80	0.20	1.58	5.73	31.41
	25^{th}%ile	1.00	0.88	0.70	0.79	0.85	0.10	0.86	0.73	2.26	0.30	2.37	7.12	32.28
	75^{th}%ile	1.00	1.00	1.00	0.84	0.89	0.12	0.90	0.82	2.50	0.40	3.44	8.54	34.77
	95^{th}%ile	1.08	1.00	1.00	0.89	0.92	0.13	0.93	0.93	2.68	0.45	4.10	9.25	35.22
	SD	0.05	0.09	0.17	0.05	0.05	0.02	0.05	0.08	0.25	0.08	0.76	1.06	1.46
Ilaro market														
Drum bean		1.17	0.82	0.58	0.70	0.82	0.09	0.70	0.71	2.13	3.15	11.79	0.27	32.17
	5^{th}%ile	0.94	0.71	0.52	0.64	0.73	0.06	0.64	0.60	1.67	1.16	7.38	0.10	30.49
	25^{th}%ile	1.12	0.77	0.53	0.67	0.78	0.08	0.66	0.65	1.92	1.99	10.22	0.20	31.20
	75^{th}%ile	1.24	0.88	0.62	0.74	0.86	0.11	0.74	0.76	2.32	4.00	13.05	0.30	32.91
	95^{th}%ile	1.34	0.94	0.69	0.79	0.91	0.13	0.78	0.85	2.60	6.01	15.80	0.45	34.51
	SD	0.11	0.07	0.06	0.05	0.06	0.02	0.05	0.08	0.31	1.45	2.42	0.10	1.41
Honey beans		1.01	0.73	0.53	0.72	0.73	0.06	0.75	0.72	1.67	0.19	2.84	6.85	32.22
	5^{th}%ile	0.90	0.65	0.46	0.66	0.67	0.05	0.69	0.64	1.41	0.10	1.52	5.04	30.02
	25^{th}%ile	0.96	0.70	0.50	0.70	0.71	0.06	0.73	0.69	1.57	0.10	1.61	5.15	32.00
	75^{th}%ile	1.05	0.75	0.55	0.75	0.75	0.07	0.77	0.76	1.75	0.20	3.68	7.78	32.52
	95^{th}%ile	1.15	0.80	0.60	0.77	0.80	0.08	0.83	0.82	1.99	0.30	5.17	9.34	34.17
	SD	0.07	0.05	0.04	0.04	0.04	0.01	0.04	0.05	0.18	0.07	1.24	1.52	1.02
Sokoto White		1.04	0.84	0.65	0.80	0.82	0.09	0.84	0.81	2.14	0.29	2.97	7.55	32.55
	5^{th}%ile	0.87	0.76	0.56	0.75	0.73	0.06	0.75	0.73	1.67	0.15	1.57	5.38	29.68
	25^{th}%ile	1.01	0.81	0.63	0.77	0.81	0.09	0.82	0.76	2.05	0.20	2.26	6.54	30.96
	75^{th}%ile	1.11	0.91	0.68	0.82	0.85	0.10	0.87	0.85	2.27	0.30	3.31	8.02	34.17
	95^{th}%ile	1.12	0.92	0.71	0.86	0.89	0.12	0.91	0.93	2.51	0.40	4.55	9.41	35.22
	SD	0.07	0.06	0.05	0.04	0.05	0.02	0.05	0.07	0.23	0.08	0.91	1.23	1.82

L – length; *W* – width; *T* – thickness; SP – sphericity; *GMD* – geometric mean diameter; *UV* – unit volume; *AM* – arithmetic mean diameter; *AR* – aspect ratio; *SA* – surface area; *UW* – unit weight; ρ – true sensity; *V* – rerminal velocity, θ – angle of repose; SD – standard deviation

The sphericity, unit volume, terminal velocity, and unit weight significantly differed across the locations and the varieties. For drum beans in Ibogun, the sphericity, unit volume, terminal velocity, and unit weight were 0.73, 0.11 cm^3, 0.31 $m·s^{-1}$, and 2.83 g, respectively, while for Ilaro, it was 0.70, 0.09 cm^3, 0.27 $m·s^{-1}$, and 3.15 g, respectively. For honey beans in Ibogun, the sphericity, unit

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Table 3. Analysis of variance (ANOVA) for the cowpea from different locations

Parameter	Ibogun			Ilaro		
	Drum beans	Honey beans	Sokoto White	Drum beans	Honey beans	Sokoto White
Length	1.04[a]	0.99[b]	1.01[b]	1.17[a]	1.01[b]	1.04[b]
Width	0.96[a]	0.70[b]	0.95[a]	0.82[a]	0.73[b]	0.84[a]
Thickness	0.88[a]	0.52[b]	0.89[a]	0.58[a]	0.53[b]	0.65[c]
Sphericity	0.73[a]	0.72[a]	0.81[b]	0.71[a]	0.72[b]	0.79[c]
Geometric mean	0.86[a]	0.71[b]	0.87[a]	0.82[a]	0.73[b]	0.83[a]
Unit volume	0.11[a]	0.06[b]	0.11[a]	0.09[a]	0.06[b]	0.09[a]
Arithmetic mean	0.74[a]	0.74[a]	0.88[b]	0.70[a]	0.76[b.]	0.84[c]
Aspect rtio	0.73[a]	0.72[a]	0.78[b]	0.71[a]	0.72[a]	0.82[b]
Surface area	2.31[a]	1.59[b]	2.34[a]	2.13[a]	1.67[b]	2.14[a]
Unit weight	2.83[a]	0.18[b]	0.33[c]	3.15[a]	0.19[b]	0.29[c]
True density	12.17[a]	2.95[b]	2.82[b]	11.79[a]	2.84[b]	2.97[b]
Terminal velocity	0.31[a]	6.92[b]	7.62[b]	0.27[a]	6.85[b]	7.55[b]
Angle of repose	31.13[a]	32.94[a, b]	33.54[b]	32.17[a]	32.22[a]	32.55[a]

Values in the same row and sub-table not sharing the same subscript are significantly different at $P < 0.05$ in the two-sided test of equality for column means

Table 4. Analysis of variance (ANOVA) for the cowpea of different variety

Parameters	Drum beans		Honey beans		Sokoto White	
	Ibogun	Ilaro	Ibogun	Ilaro	Ibogun	Ilaro
L	1.04[a]	1.17[b]	0.99[a]	1.01[a]	1.01[a]	1.04[b]
W	0.96[a]	0.82[b]	0.70[a]	0.73[b]	0.95[a]	0.84[b]
T	0.88[a]	0.58[b]	0.52[a]	0.53[a]	0.90[a]	0.65[b]
SP	0.73[a]	0.71[b]	0.72[a]	0.72[a]	0.81[a]	0.80[a]
GMD	0.86[a]	0.81[b]	0.71[a]	0.73[b]	0.86[a]	0.83[b]
V	0.11[a]	0.09[b]	0.06[a]	0.07[b]	0.11[a]	0.09[b]
AMD	0.74[a]	0.70[b]	0.74[a]	0.76[b]	0.88[a]	0.84[b]
AR	0.73[a]	0.71[a]	0.72[a]	0.72[a]	0.78[a]	0.82[b]
SA	2.31[a]	2.13[b]	1.59[a]	1.67[b]	2.34[a]	2.14[b]
UW	2.83[a]	3.15[a]	0.18[a]	0.19[a]	0.33[a]	0.29[a]
ρ	12.17[a]	11.79[a]	2.95[a]	2.84[a]	2.82[a]	2.97[a]
V	0.31[a]	0.27[a]	6.92[a]	6.85[a]	7.62[a]	7.55[a]
θ	31.13[a]	32.17[a]	32.94[a]	32.22[a]	33.54[a]	32.55[a]

values in the same row and sub-table not sharing the same subscript are significantly different at $P < 0.05$ (the two-sided test of equality for column means); *L* – length (cm); *W* – width (cm); *T* – thickness (cm); SP – sphericity; *GMD* – geometric mean diameter (cm); *V* – unit volume (cm^2); *AMD* – arithmetic mean diameter (cm); AR – aspect ratio; *SA* – surface area (cm^2); UW – unit weight (g); ρ – true sensity (g·cm^{-3}); *V* – terminal velocity (m·s^{-1}), θ – angle of repose (°)

volume, terminal velocity, and unit weight were 0.72, 0.06 cm^3, 6.92 m·s^{-1}, and 0.18, respectively, while for Ilaro it was 0.72, 0.06 cm^3, 6.85 m·s^{-1}, and 0.19 g, respectively. For Sokoto white from Ibogun, the sphericity, unit volume, terminal velocity, and unit weight were 0.81, 0.11 cm^3, 7.62 m·s^{-1}, and 0.33 kg, respectively, while for Ilaro, it was 0.80, 0.09 cm^3, 7.55 m·s^{-1}, and 0.29 g, respectively. The sphericity of cowpea grains for cultivar BRS Guariba has mean values of 73.9%, according to Oba et al. (2019). In India, cowpea beans from the colour group had mean values of 87.64%, according to Hamid et al. (2016). Davies and Zibokere (2011) showed sphericity ranging from 67 to 79% for many cowpea cultivars in Nigeria. Theertha et al. (2014) for black grain; Ehiem et al. (2016) for *Canarium Schweinfurthii* Engl. fruits; and Yalcin (2006) for cowpea seed all reported a similar pattern.

For drum beans in Ibogun, the geometric mean, aspect ratio, and arithmetic mean were 0.86 cm, 0.73, and 0.73 cm, respectively, while for Ilaro, the respective values were 0.82 cm, 0.71, and 0.70 cm. For honey beans in Ibogun the geometric mean, aspect ratio, and arithmetic mean were 0.71 cm, 0.72, and 0.74 cm, respectively, while for Ilaro, it was 0.73 cm, 0.72, and 0.75 cm, respectively. The geometric mean, aspect ratio, and arithmetic mean of Sokoto white in Ibogun were significantly different from that of Ilaro. For Sokoto white in Ibogun, the geometric mean, aspect ratio, and arithmetic mean were 0.86 cm, 0.78, and 0.87 cm, respectively, while for Ilaro, it was, 0.82 cm, 0.81, and 0.84 cm, re-

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spectively. The results were obtained similar to the observation reported by Adanu et al. (2022)

The true density and the angle of repose of the varieties from Ilaro and Ibogun had no significant difference, unlike the surface area. For drum beans in Ibogun, the true density, angle of repose, and surface area were 12.17 g·cm^{-3}, 31.13 °, and 2.31 cm^2, respectively, while for Ilaro, it was 11.79 g·cm^{-3}, 32.17 °, and 2.13 cm^2, respectively. For honey beans in Ibogun, the true density, angle of repose, and surface areas were 2.95 g·cm^{-3}, 32.94 °, and 1.59 cm^2, respectively, while for Ilaro it was 2.84 g·cm^{-3}, 32.22 °, and 1.67 cm^2, respectively. For Sokoto white in Ibogun the true density, angle of repose, and surface area were 2.81 g·cm^{-3}, 33.54 °, and 2.34 cm^2, respectively, while for Ilaro, it was 2.97 g·cm^{-3}, 32.55 °, and 2.14 m^2, respectively. Chukwu and Sunmonu (2010) reported the length, width, and thickness of Sampea 7 as 9.48, 6.75, and 5.35 mm, respectively, which is within the range of that of honey and Sokoto white cowpea. According to Ogunngbo et al. (2018), in a study of Nigerian cowpea cultivars, values ranged from 23.69 to 38.01 °. Silveira et al. (2019) discovered that the angle of repose for fava bean grains ranged from 27.67 to 40.67 °. Similar results were reported by Davies and Zibokere (2011) for three or four of the cowpea cultivars they examined. According to Mohsenin (1986), the angle of internal friction indicates the lowest positioned angle that will ensure a constant flow of materials.

Cleaning efficiency. The result in Table 5 shows the efficiency of the MVCC in cleaning the varieties of beans. It shows that there is a better quality of cleaning when the product is run twice. After the first cleaning, the total efficiency is 78, 74 and 59%, respectively. The first cleaning was affected by the efficiency of removing bad products. The second cleaning improved the efficiency of removing the bad products, leading to a higher total efficiency of 83, 86, and 80%, respectively. The MVCC performed best in cleaning drum beans, followed by homey beans and Sokoto white. Sokoto White had the least total efficiency because it did not perform well in separating the good products, even though it had an efficiency of 96% in removing the bad products. This can be attributed to the fact that it had the smallest length compared to drum and honey beans. According to Irtwange (2009), a cleaning efficiency of 95.60% was achieved with a feed rate of 120.72 g and a moisture content of 11.06%. The cleaning efficiency decreased at different moisture levels as the feed rate was raised from 6 to 10 kg·h^{-1} at 13.65% moisture content. This demonstrates that the cleaning efficiency increases with the amount of dry material to be threshed. Muhammad-Bashir et al. (2018) reported cleaning efficiency of 88.90% at the feed rate of 1 kg·h^{-1} and threshing cylinder speed of 472 rpm, while Mohammed et al. (2013) obtained the highest average cleaning efficiency of 97.72% at the moisture content of 9.01% and threshing cylinder speed of 1 200 rpm.

CONCLUSION

This study establishes the developmental process of a multi-variety cowpea cleaner (MVCC) for three popular cowpea varieties in southwestern Nigeria (honey, drum, and Sokoto white beans). Samples were collected from two markets. The physical properties of the cowpeas were determined and applied when designing the MVCC. These properties were observed to be significantly different in varieties and locations. Depending on the cowpea varieties and locations, the length, width, thickness, spheric-

Table 5. The cleaning efficiency of multi-variety cowpea cleaner

Parameter	Honey beans		Drum beans		Sokoto white beans	
	first cleaning	second cleaning	first cleaning	second cleaning	first cleaning	second cleaning
GR (g)	10.7	9.8	30.4	18.2	53.1	33.8
BR (g)	40.2	46.9	23	46.9	9.3	43.1
GP (g)	190.4	186.4	192.6	182.1	184.7	171.3
BP (g)	8.7	6.9	4	2.8	2.9	1.8
EG (%)	95	95	86	91	78	84
EB (%)	82	87	85	94	76	96
ET (%)	78	83	74	86	59	80

GR – good reject; BR – dad reject; GP – good product; BP – bad product; EG – efficiency of good; EB – efficiency of bad; ET – total efficiency

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ity, geometric mean, unit volume, arithmetic mean, aspect ratio, surface area, unit weight, true density, terminal velocity, and angle of repose were observed to be 0.99–1.17 cm, 0.70–0.96 cm, 0.53–0.89 cm, 0.71–0.81, 0.71–0.87 cm, 0.06–0.11 cm^3, 0.70–0.88 cm, 0.71–0.82, 1.59–2.34 cm^2, 0.18–3.15 g, 2.84–12.17 $g \cdot cm^{-3}$, 0.27–7.62 $m \cdot s^{-1}$, and 31.13–33.54 °, respectively. The MVCC was designed to have a hopper, screens, rotor, winnowing unit, and frame. A preliminary evaluation of the MVCC revealed that separation efficiency after the first cleaning was 59–78%, but after the second cleaning, the efficiency increased to 80-86%, depending on the cowpea varieties. This presents a solution to the poor quality of cowpea in the local markets in southwestern Nigeria.

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