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Research article

Engineering properties of sorghum bioguma-variety for designing appropriate thresher and chopper machine

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Abstract: Sorghum is a versatile plant with various parts that can be utilized. However, information on the physical and mechanical properties of the sorghum plant is crucial for designing agricultural machinery for primary handling processes such as threshing and chopping. This study aimed to determine the technical characteristics of sorghum plants (Bioguma variety) including the physical and mechanical properties of the stems, leaves, panicles and seeds to design a configuration system concept for threshing and chopping machines capable of processing sorghum plants with high moisture content immediately after harvesting. The study used a descriptive method and included samples of sorghum plants randomly taken from fields in Majalengka and Bogor, Indonesia. The physical and mechanical properties were measured using several replications, ranging from 3 to 30 depending on the parameter. The sorghum plants were harvested at at ages 80, 90 and 108 days after transplanting (DAT). It was found that the moisture content of sorghum stem and seeds decreased with the increase of plant ages where stem ranged between 84.18–79.81 %wb and seeds ranged between 51.7–29.4 %wb. The result revealed that planting ages influenced its properties including stem properties and seed properties. Longer DAT increased the stem hardness from 290.64 ± 29.41 to 350.00 ± 0.81 N and seed hardness from 8.2 ± 1.7 to 44.9 ± 5.4 N but decreased the tensile force of seed form panicles from 16.7 + 3.2 to 6.0 ± 0.8 N. The data on stem strength and seed hardness provide important considerations for the development of several equipment for sorghum processing. The findings of this study can serve as a basis for designing effective and efficient threshing and chopping machines for sorghum plants at high moisture content.

Keywords: chopper machine; sorghum plants; technical characteristics; thresher design

1. Introduction

Sorghum (*Sorghum bicolor* L.) is a cereal grain plant that is a member of the grass family (*Poaceae*). It is an important food crop and source of income for millions of people in the semi-arid tropics of Africa and Asia [1]. Sorghum is the fifth most important cereal crop globally after rice, wheat, barley and maize and is the staple food of around 500 million people [2,3]. Directly chopped sorghum leaves can be used for ruminant feed in the form of silage [4]. However, a study notes that although sorghum has potential as a source of food and industrial products, its utilization is constrained by several factors including the lack of efficient post-harvest processing technologies [5], especially sorghum with different varieties. Another study highlights the need for research to develop improved post-harvest management practices for sorghum and other crops to reduce losses and enhance food security [1,6,7]. According to Ndukwu and Ejirika [8], a crop's physical characteristics and in most cases its cultivar have the greatest impact on an agro-processing machine's ability to adapt. As also stated by Li et al. [9] and Ndukwu et al. [10], the physical properties of crops are part of the contact mechanics in post-harvest processing and a major determinant in intelligent harvesting. Information about the physical and mechanical properties of the sorghum plant is needed for the primary handling process of the sorghum plant such as threshing the seeds and chopping the stems directly from harvest in the field so that all parts can be utilized. This is equivalent to the opinion of [11] which states that the physical characteristics of sorghum seeds are needed to design various types of agricultural machinery such as threshers and choppers. For immediate post-harvest processes with high water content (20-30 %wb) such as threshing of sorghum panicles and chopping of sorghum stems the physical and mechanical characteristics of the sorghum plant are needed. It is required for the hold-on type of threshing of sorghum panicles/seeds because the sorghum plant stems are clamped during threshing, thus, it is necessary to consider relevant information on seed moisture content, the tensile strength of seeds from panicles, panicle hardness, panicle-seed dimensions, seed-specific gravity, seed-to-panicle, plant ratio and terminal velocity. For the enumeration, information on the physical and mechanical properties of the stems and in the form of a pile of stems is needed including water content, hardness, specific gravity, dimensions, weight and cutting force of the sorghum stalks. According to Gely et al. [12] a thorough understanding of the physical properties of sorghum grains is helpful to improve the technology associated with operations and equipment related to post-harvest processes such as cleaning, sorting, transport, ventilation, drying and storage.

Several studies have reported some physical and mechanical properties of sorghum seeds [11–13] as affected by moisture content. However, these studies use different varieties and are not based on harvesting age. In addition, the research also only focused on sorghum seeds and without observing the sorghum plant as a whole. Thus, there is a gap in research regarding the engineering properties of the Bioguma variety which is necessary for the development of appropriate sorghum processing machines capable of directly processing seeds and stems at high moisture content and reducing processing costs such as panicle drying and seed milling. This research aims to fill this gap by obtaining technical characteristics of the sorghum plant (seeds, panicles and stems) which can serve as the basis for designing a configuration system concept for threshing and chopping machines that are capable of handling various sorghum seed varieties and plant conditions with seed moisture content ranging from 20–30% and chopped stems with moisture content of 76–90%. The findings of this research will be advantageous for the design and development of efficient sorghum processing machines. This research aimed to provide technical characteristics of the entire sorghum plant under different ages including the physical and mechanical properties of its stems, leaves, panicles and seeds to develop a configuration system concept for threshing and chopping machines. The study focuses specifically on the engineering properties of the Bioguma variety of sorghum plants, especially from Indonesia region.

2. Materials and methods

2.1. Sorghum raw materials

The material consists of sorghum Bioguma varieties grown on the fields of Majalengka and Garut farmers with latosol soil conditions and dry land. Bioguma sorghum varieties were harvested at the age of 80, 90 and 108 days after transplanting (DAT).

2.2. Physical properties measurements of sorghum stalks and seeds

The physical characteristics of the sorghum plant consisted of the stem, panicle, and seed components. The parameters measured include plant height or length, dimension (diameter of main branch, diameter of panicle and seeds dimension), mass (plants, panicles and seeds) and bulk density (plant and seed piles). The method used in measuring the physical characteristics of the sorghum plant was a direct measurement with a measuring instrument namely a ruler, caliper and tape measure. The measurement of seed dimension is shown in Figure 1 based on [14–17]. The height or length of the plant was measured from the base of the main stem which was cut using a machete at a height of 10–20 cm from the ground to the top of the leaf. Figure 2 shows the measurement of stem diameter measured from the base of the main stem on the first internode after being cut at the lowest internode because the height or length of this plant is used to design conveyors for threshing and chopping machines. Bulk density was determined by weighing a sample of the material in the form of a pile of stems and then measuring the dimensions of the pile of stems (width and thickness).

The mass of stems and stem piles was measured by direct weighting per plant and plant pile. Bulk density was known to take into account the frictional pressure on sorghum plants calculated from the sample mass and plant volume [18] as in Equation (1).

$$\rho = \frac{m}{v} \tag{1}$$

where ρ is bulk density (g/cm^3), m is sample weight (g) and v is volume occupied by sample (cm^3).

Figure 1. Dimensions of sorghum seeds (h: height; l: length; t: thickness).

Figure 2. Measurement of the diameter of the main stem and panicle stem.

2.3. Mechanical properties measurements of sorghum stalks and seeds

The mechanical characteristics observed were the tensile strength of the seeds from the panicle, the angle of seed dropping, terminal velocity, stem cutting force, stem hardness and plant friction coefficient. Measuring the mechanical characteristics of a sorghum plant is necessary to design a threshing machine and chopping machine as well as a conveyor system so that it becomes an appropriate technology that can help shorten the processing time of sorghum plants into poultry and ruminant feed.

2.3.1. Tensile strength of panicles

Tensile strength was measured by pulling the sorghum seeds from the panicles so that deformation occurred (Figure 3), namely, the sorghum seeds broke off from the panicle litter. The data obtained was in the form of changes in length and load which are then displayed as a stress-strain graph. The measuring tool used to test the tensile strength of sorghum seeds from panicles is a tensile strength tester (strain gauge) model ELK-500 (Yueqing Elecall Electric Co., Ltd., China) with an accuracy of 0.01 kg with maximum capacity of 50 kg and vernier callipers (Mitutoyo America Corp., USA) with an accuracy of 0.02 mm. To calculate the maximum tensile stress (σ_{max}), the following formula was used [19] as in Equation (2).

$$\sigma_{max} = \frac{F_t}{A} \tag{2}$$

$$A = \frac{1}{4}\pi \times d^2 \tag{3}$$

where σ_{max} is maximum tensile stress (N/m^2), F_t is tensile force (N), A is cross-sectional area of sorghum stem (m^2) and d is diameter of sorghum stem (m).

The change in stress divided by the change in strain is called the modulus of elasticity. The modulus value is calculated as the linear slope of the stress-strain curve based on the regression method.

Figure 3. Sorghum seeds are pulled from the litter of the small stalks of the panicles.

2.3.2. Bulk angle of repose

The pouring angle was formed between the flat surface and the sloping side of the outpouring when several sorghum seeds were poured rapidly and flowed by gravity over the flat surface (Figure 4). The measurement of the pouring angle was carried out to find out how much the slope was formed when the sorghum seeds came out of the hole where whole seeds were removed from the hold-on type threshing machine. The pouring angle can be calculated using Equation 4 [20,21].

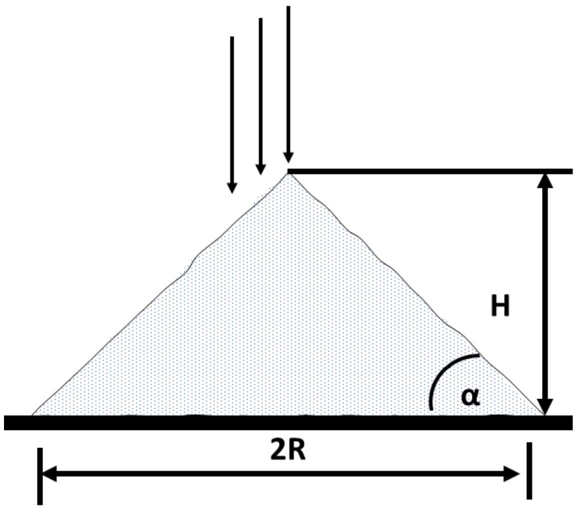

Figure 4. Measurement of Sorghum grain angle of repose.

$$\alpha = arc\tan\frac{H}{R} \quad (4)$$

where α is angle of repose (°), H is height of sorghum seeds (cm) and R is radius of sorghum grain demand base circle (cm).

2.3.3. Terminal velocity

Terminal velocity is the velocity at which an object changes until one condition where the drag is equal to the gravitational force [22]. In this case, terminal velocity of sorghum seed was measured by using an adjustable fan as shown in Figure 5.

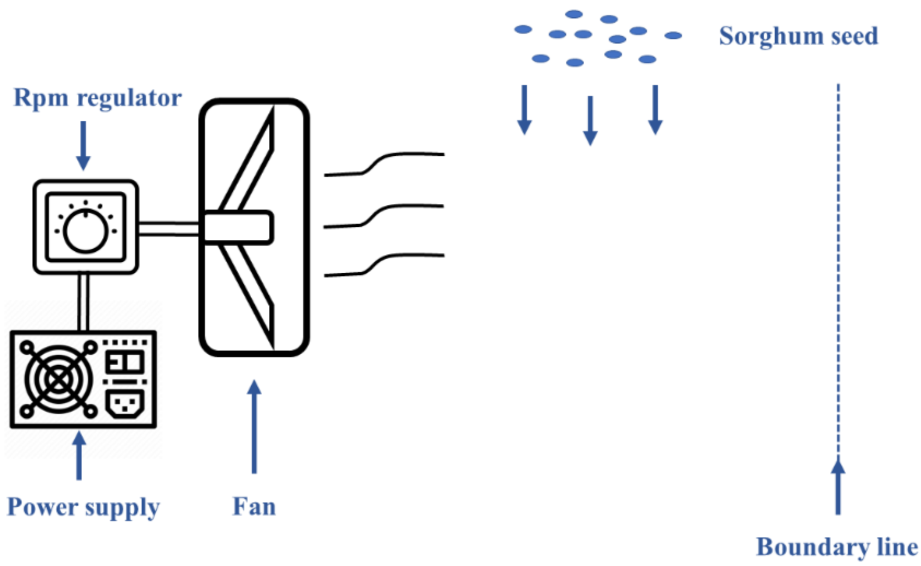

Figure 5. Method for terminal velocity measurement.

2.3.4. Hardness and tensile strength of stems and seeds

Stem hardness was measured by piercing or pressing the sorghum stems and seeds so that deformation occurred, namely the sorghum seeds or stems were damaged. The data obtained is in the form of changes in length and changes in load which are then displayed in the form of a stress-strain graph. The measuring instrument used in testing the hardness of sorghum stalks is the TA-XT Plus Texture Analyzer (Stable Micro Systems, UK) (Figure 6) with a loadcell capacity of 50 kg with a speed of 0.2 mm/s.

For stem tensile strength measurement, the samples of sorghum stem with a diameter of 0.62–1.91 mm and a length of 100 mm were prepared. The measurement of the diameter of the sample was carried out for the purposes of calculating the maximum tensile stress of the sorghum plant stems. To calculate the maximum tensile stress of sorghum stems (σs_{max}) the Equation 5 was used [19].

$$\sigma s_{max} = \frac{F_t}{A} \quad (5)$$

where σs_{max} is maximum tensile stress of stem (N/m^2), F_t is tensile force (N) and A is cross-sectional area of sorghum stalks (m^2).

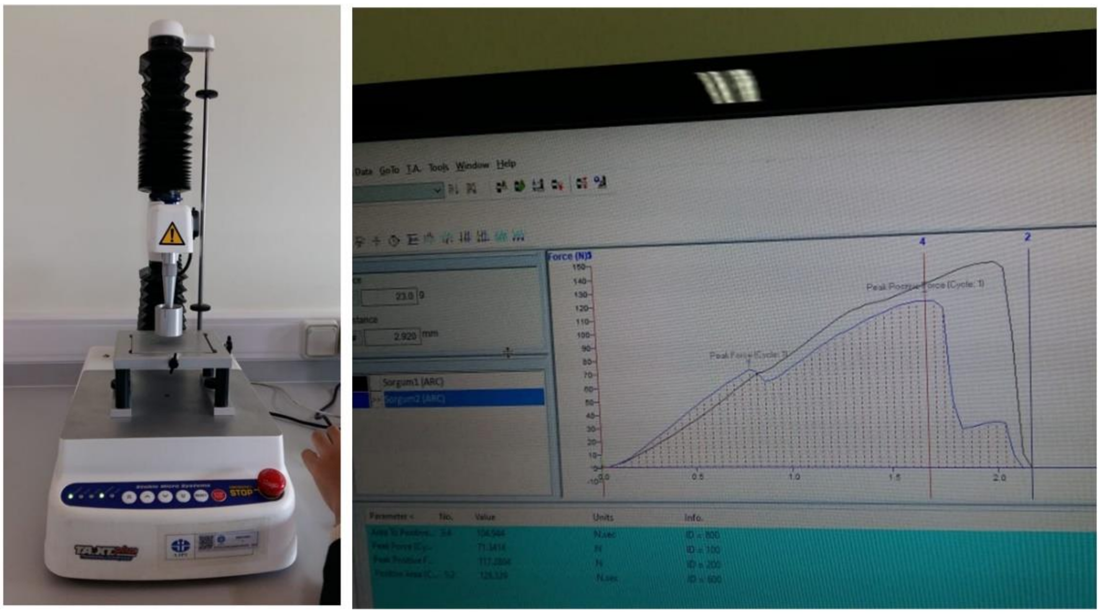

Figure 6. Texture analyzer used for measuring hardness of stems.

The change in stress divided by the change in strain is called the modulus of elasticity. The modulus value is calculated as the slope of the linear part of the stress-strain curve based on the regression method.

2.3.5. Cutting force

The cutting force is obtained by using the cutting force method. The ratio of the cutting resistance to the cross-sectional area of the cut sorghum stem is needed to calculate the specific cutting resistance. The cutting force acts when the strain gauge installed with a digital knife is pulled vertically downwards (Figure 7) and the cutting load will be read. The value reads in force units (N). The cutting resistance is calculated using the formula in Equation 6.

Figure 7. Cutting force measurement.

$$F_{BN} = \frac{F_{L1} \times L_F}{L_{TP} + R_b} \tag{6}$$

where F_{BN} is stalk cutting resistance (N), F_{L1} is force measured on the arm (N), L_{TP} is length of cutting resistance arm (m), R_b is radius of sorghum stem (m) and L_F is length of force arm (m).

2.3.6. Friction coefficient

The coefficient of friction between the plants and the steel plate was measured by placing a vertical load on the sorghum plant and then pulling the load horizontally with a measuring scale while the sorghum plant was in a static state. The load used is a steel plate weighing 3 kg with dimensions of 25 × 10 × 5 cm. The plant friction coefficient is obtained from the relationship between the normal force and the friction force according to Equation 7.

$$F_g = \mu \times N \tag{7}$$

where F_g is friction force (N), μ is friction coefficient and N is normal force (N).

3. Results and discussion

3.1. Sorghum plant physical characteristics

Determining the sorghum plant's physical properties is necessary for designing a hold-on thresher and chopping machine. The sorghum plants studied from the Bioguma variety included plant dimensions and plant piles (p × l × t), plant/pile weight, plant/pile density and seed to plant/panicle ratio on the condition of sorghum plants after harvest directly from the field and then processed into feed. Plant density is needed for a conveyor design for carrying plant piles to a hold-on thresher with a clamping system on sorghum plant panicles. The physical properties of the seeds and plants of the sorghum Bioguma variety can be seen in Table 1.

Table 1. Average physical properties of sorghum stems and seeds based on DAT and water content.

No	Physical parameters	Plant age (moisture content of stems, seeds (%wb))					
		80 DAT (84.18%, 51.7%)		90 DAT (80.64%, 30.7%)		108 DAT (79.81%, 29.4%)	
		Range	Average	Range	Average	Range	Average
1	Pile width (cm)	54–26	38.00 ± 10.64	52–26	38 ± 10.64	53–26	38.00 ± 10.64
2	Pile height (cm)	16–11	14 ± 0.76	15–10	13.5 ± 0.76	14–12	13.00 ± 0.76
3	Pile weight (kg)	8.1–3.9	6.61 ± 1.27	7.6–3.7	6.11 ± 1.27	7.1–3.9	5.61 ± 1.27
4	Plant height (cm)	244–128	183.36 ± 30.69	260–182	210 ± 26.72	266–202	222 ± 10.08
5	Stem diameter (cm)	1.5–0.8	1.09 ± 0.24	1.9–1.1	1.07 ± 2.2	1.8–1.0	1.77 ± 2.1
6	Seed size:						
	l (mm)	4.98–3.95	4.81 ± 0.15	4.78–3.98	4.71 ± 0.14	4.28–3.95	4.18 ± 0.13
	w (mm)	4.53–5.88	4.15 ± 0.66	4.43–5.88	4.18 ± 0.68	4.23–5.88	4.15 ± 0.64
	t (mm)	2.85–2.49	2.68 ± 0.10	2.80–2.49	2.66 ± 0.10	2.75–2.49	2.62 ± 0.10
7	Weight:						
	Plant (g)	289–94	166.09 ± 73.19	691–154	317.73 ± 153.07	700–400	560.00 ± 15.07
	Panicle (g)	54–15	34.27 ± 14.38	178–28	74.09 ± 46.07	236.07–55.35	138.62 ± 63.08
	Seeds in one panicle (g)	46–12	27.91 ± 11.59	157–24	63.27 ± 39.81	210.72–47.60	121.43 ± 51.56
8	Seed–panicle ratio (%)	0.91–0.51	0.83 ± 0.11	0.93–0.73	0.85 ± 0.05	0.89–0.85	0.87 ± 0.01
9	1000 grain weight (g)	38–30	32.0+0.2	39–30	36.0+0.2	49–36	44.0+0.5
10	Seed diameter (cm)	0.51–0.35	0.40 ± 0.04	0.50–0.38	0.42 ± 0.04	0.50–0.39	0.45 ± 0.05
11	Litter diameter (cm)	3.3–3.0	3.10 ± 0.09	3.9–3.1	3.27 ± 2.0	3.8–3.0	4.57 ± 2.4
12	Small panicle stalk diameter (cm)	1.5–0.8	1.09 ± 0.24	1.9–1.1	1.07 ± 2.2	1.8–1.0	1.77 ± 2.1
13	Stem diameter (cm)	5.8–5.1	5.4 ± 0.19	6.1–5.1	5.8 ± 0.18	5.7–5.0	5.6 ± 0.17
14	Seed–plant Ratio (%)	22–10	17.0 ± 2.37	20–10	16.0 ± 2.17	17–9	12.0 ± 1.86
15	Seed density (kg/m^3)	78–60	64.0 ± 2.37	77–55	62.0 ± 2.17	76–54	61.79 ± 1.86
16	Stem stack density(kg/m^3)	56–40	48.70 ± 2.37	52–45	41.2 ± 2.17	58–42	49.7 ± 1.86

The physical characteristics of the Bioguma sorghum include dimensions and shape. The shape of the Bioguma sorghum at 80 DAT, 90 DAT and 108 DAT was round. The sorghum seeds' shape and the seeds' dimensions are needed as a basis for designing thresher and output outlet dimensions. Meanwhile, the ratio of both seed-to-panicle and seed-to-plant ratios is needed to determine the threshing machine's capacity and the conveyor's capacity to carry the sorghum plants to the thresher. The density of the stem stack of Bioguma sorghum has an average value of 41.2 ± 2.17 until 49.7 ± 1.86 kg/m^3. The density of plant piles is used to design the carrying conveyor capacity for the threshing machine and the conveyor capacity for the chopping machine. The density of the plant pile also determines the capacity of the hold-on type thresher and the capacity of the cross-flow type thresher. The ratio of seeds to sorghum plants is significant in designing the capacity of a sorghum threshing machine combined with a sorghum stalk chopper under conditions of high moisture content of seeds (20–30%) and stems (70–90%). According to [23], the grain ratio is needed to determine the threshing machine's capacity and the conveyor carrying the sorghum plants to the thresher.

In this study, it was found that the Bioguma variety had a mass of 1000 seeds ranging from 32–44 grams. This value is greater than the study by Gely et al. [12] which use cultivar SDK DK51 where the value ranges from 26–29 grams. This was due to the water content in this study being higher (above 29%wb) while in Gely et al. [12], the water content was below 21%wb.

3.2. Sorghum plant mechanical characteristics

Parameters of the seeds' mechanical characteristics include the seeds' pulling force from the panicle, the angle of seed dropping and the terminal velocity. A previous study reported that litter and small panicles are needed to design threshing machine designs such as topical by calculating the power requirements, the need for separatory sieve mechanisms and blowers and the total power requirement for threshing machines [24]. The mechanical properties of stems including panicle hardness, stem hardness and stem cutting force are needed to design the components of a sorghum stalk chopping machine including knife hardness, number of blades, chopped length, driving force requirements and others. The average mechanical properties of sorghum stems and seeds are presented in Table 2.

Table 2. Mechanical properties of sorghum stems and seeds of Bioguma varieties based on DAT and moisture content.

No	Physical parameters	Plant ages (moisture content of stems, seeds (%wb))					
		80 DAT (84.18 %, 51.7%)		90 DAT (80.64%, 30.7%)		108 DAT (79.81%, 29.4%)	
		Range	Average	Range	Average	Range	Average
1	Tensile force of seeds from panicles (N)	26.2–13.8	16.7+3.2	16.5–12.0	13.8 ± 1.4	7.83–5.07	6.0 ± 0.8
2	Stem hardness(N)	344–229	290.64 ± 29.41	380–260	315.91 ± 34.85	440–280	350.00 ± 0.81
3	Seed hardness (N)	10.5–5.8	8.2 ± 1.7	13.8–5.3	9.76 ± 2.4	54–30	44.9 ± 5.4
4	Terminal velocity of litter (m/s)	2.9–2.1	2.53 ± 0.23	2.7–2.0	2.43 ± 0.25	2.6–1.9	2.23 ± 0.26
5	Terminal velocity of small panicle stalk (m/s)	2.7–1.8	2.33 ± 0.25	2.6–1.8	2.33 ± 0.26	2.5–1.8	2.23 ± 0.28
6	Terminal velocity of chopped rod (m/s)	2.9–2.1	2.45 ± 0.34	2.9–2.1	2.45 ± 0.34	2.9–2.1	2.45 ± 0.34
7	Terminal velocity of chopped leaves (m/s)	2.9–2.1	2.34 ± 0.32	2.9–2.1	2.45 ± 0.34	2.9–2.1	2.45 ± 0.34
8	Terminal velocity of seeds (m/s)	14.2–11.3	12.2 ± 0.89	14.2–11.4	12.3 ± 0.49	13.2–11.3	12.1 ± 0.59
9	Coefficient of friction (N)	0.93–0.81	0.86 ± 0.06	0.87–0.75	0.80 ± 0.05	0.83–0.71	0.76 ± 0.03
10	Bar cutting force (N)	334–220	290.64 ± 28.32	360–260	315.91 ± 24.85	423.4–223.7	354.00 ± 0.71
11	Tensile strength stems (GPa)	3.29–0.64	1.67 ± 0.97	0.44–0.26	0.33 ± 0.06	0.44–0.26	0.33 ± 0.06
12	Angle of repose (°)	35.5–25.1	34.3+1.67	34.2–23.8	33.0 ± 3.72	33.70–22.10	32.34 ± 0.15

3.3. Tensile force of seeds from panicles

The tensile force of the sorghum seeds from the panicle of sorghum causing deformation occurs, namely the sorghum seeds break or cracks occur in the range of the maximum tensile force value of 26.2 N at a seed moisture content of 51.7%, 16.5 N at a moisture content seed 30.7% and 7.85 N at a seed moisture content of 29.4%. The results of this study indicate that the tensile strength of the seeds decreases with decreasing moisture content. This research is not in line with research by [25] on patchouli plants that showed the higher the water content, the lower the tensile strength of the patchouli stems. Likewise, it is also not in line with research on bamboo plants which shows that the lower the water content of bamboo, the higher the tensile strength of bamboo [26]. This is because the seeds are attached to the leaf litter on the tip of the small panicle stalk and not on the panicle stalk. So, the withdrawal process occurs on the leaf litter and if the leaf litter dries out the sorghum seeds will fall off more easily. Likewise, this is because when an object experiences a pull, the object experiences an internal force and an external force in the process of its attraction. The external force is the force that changes the initial state of the object while the internal force is the force that comes from within the object. The results of the tensile force of sorghum seeds from panicles based on different planting ages are presented in Figure 8.

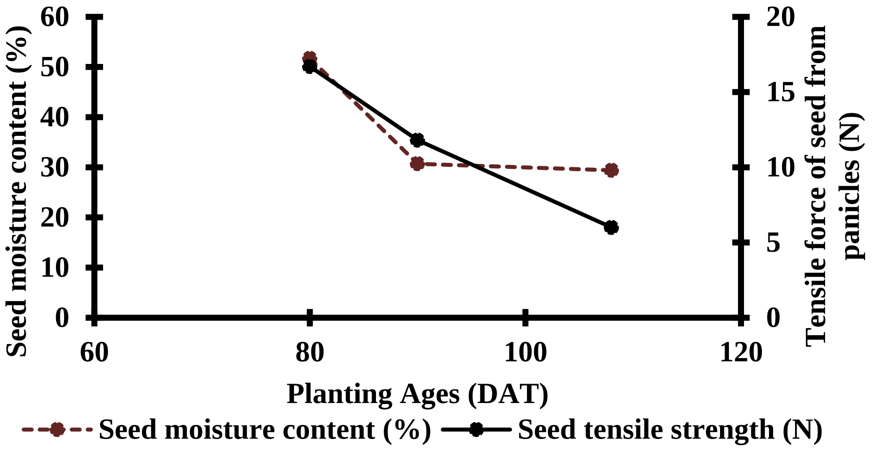

Figure 8. Tensile force test of seed from panicles at various seed moisture contents and planting ages.

3.4. Hardness of sorghum stems and seeds

Stem and seed hardness is the property of resistance to breaking due to the applied compressive force. Hardness is the ability to withstand pressure that causes the stems/seeds to break. The hardness of the samples was shown on the intact stems and seeds. The Bioguma variety has a hardness of around 8.2–44.9 N. This value was similar to that of the Seredo variety but lower than the Serena and Kari-mtama varieties [11]. The stem hardness of the Bioguma variety ranges from 290–350 N which is still below the hardness range of sugarcane stems around 775 N [27]. The hardness of sorghum stems and seeds will be higher with lower stem moisture content and seed moisture content. The effect of DAT on moisture content and sorghum grain hardness is presented in Figure 9 and the effect of DAT on stem moisture content and stem hardness is presented in Figure 10.

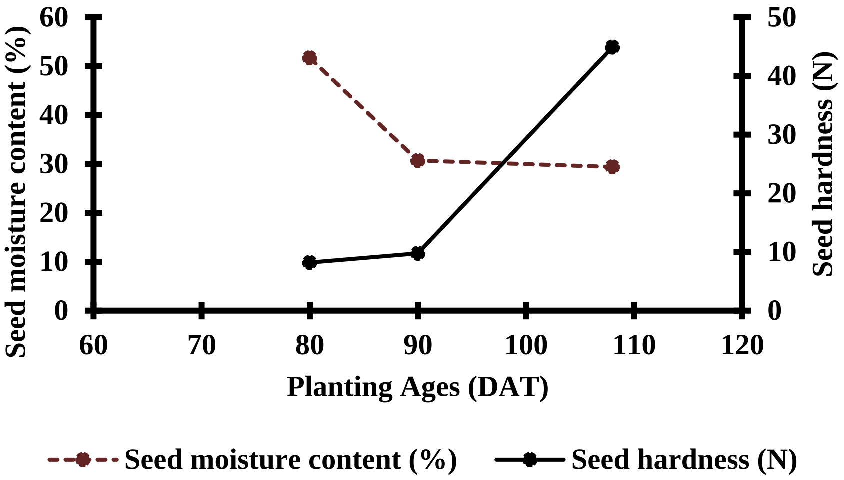

Figure 9. Influence of DAT on moisture content and sorghum grain hardness.

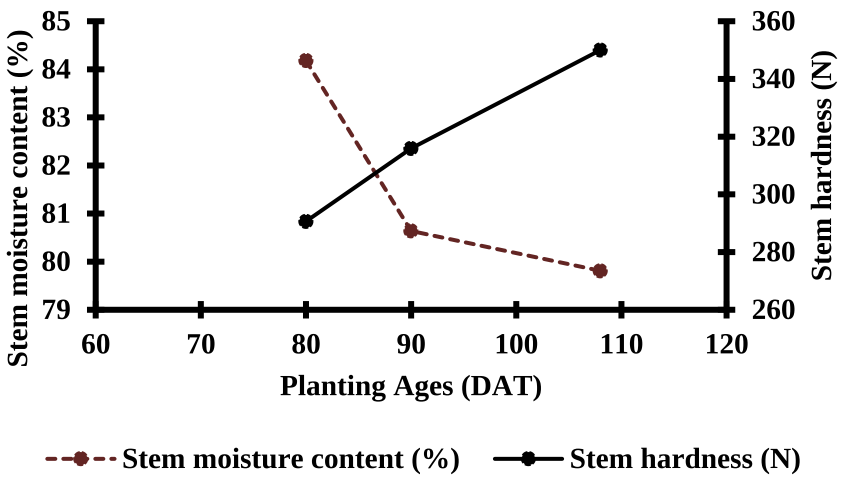

Figure 10. Influence of DAT on stem moisture content and stem hardness.

3.5. Angle of repose and coefficient of friction

The pouring angle is needed for the design of the slope of the outlet for threshing beans. The sorghum grain pouring angle was carried out three times with an average pouring angle of 34.3 ± 1.67° at a condition of 51.7% seed moisture content, an average pouring angle of 33.0 ± 3.72° at a seed moisture content of 30.7% and an average pouring angle of 32.34 ± 0.15° at 29.4% seed moisture content. This indicates that an increase in the bulk angle can occur with an increase in water content. In accordance with research conducted by [28] that the corn bulk angle increased significantly from 49° to 58° in the range of 4.73% to 22% moisture content. [29] recommended using galvanized iron for the manufacture of grain seed vessels with a tilt angle of 40°. The characteristic coefficient of friction based on the calculation of Equation 6 above an average of 0.76 at a moisture content of 29.4% is necessary for the design of the rod carrying conveyor to the chopping machine.

3.6. Terminal velocity

The terminal velocity of leaf litter, seeds and small panicle stalks which are part of the sorghum panicle is used as the basis for designing the separation of impurities from threshed seeds in a hold-on type sorghum threshing machine. The measurement results showed that the terminal velocity of the litter was around 2.9–2.10 m/s, small panicle stalks around 2.6–1.80 m/s, leaf chopping around 2.9–2.10 m/s, stem chopping around 2.9–2.10 m/s and seeds around 14.1–11.2 m/s. This can be the basis for determining the blower speed above 2.9 m/s and below 14 m/s so that litter and other debris are blown away but not the sorghum seeds. The results of the terminal velocities of sorghum seeds and other impurities are in line with several studies on the separation of impurities in grains, stalks and leaves that have been carried out by several researchers aimed at improving the quality and quality of the product. Gorial and O'callaghan [30] performed particle separation using horizontal airflow. Five different samples were used in this experiment wheat germ mix, different grain mix (soybean, pea, Adzuki bean, mung bean, sorghum, millet and oilseed rape), wheat germ mix, oilseed rape mix and soybean/grass seed mix. Sacks with a width of 20 cm each are attached to the dispensing hole. Air flow is blown with a speed of 8 m/s and 11 m/s on a continuous channel with a length of 4 m using a blower with a 2 kW motor power. In order to eliminate the effects of turbulence and eddy, there are two fine screens placed on the feeder line which is close to the discharge section. The results showed that the effectiveness of separating grain was influenced by air velocity, grain size and density. The air velocity of 11 m/s causes the material to float along the channel and most of the husks are accommodated at the farthest outflow. However, the low air velocity (8 m/s) causes most of the mixture to be contained in the three sacks near the feed, the low air velocity combined with the high feed rate results in poor separation. At an airspeed of 11 m/s, 1.1% of the soybean seeds are found in the grass seeds and 0.85% of the grass seeds are found in the soybeans. However, when the air velocity decreased to 8 m/s half as much soybean was found in the grass seeds and 3.3% of the grass seeds remained among the soybeans. At a continuous channel length of 160 cm and an air speed of 11 m/s, it allows the wheat to be separated by 95%.

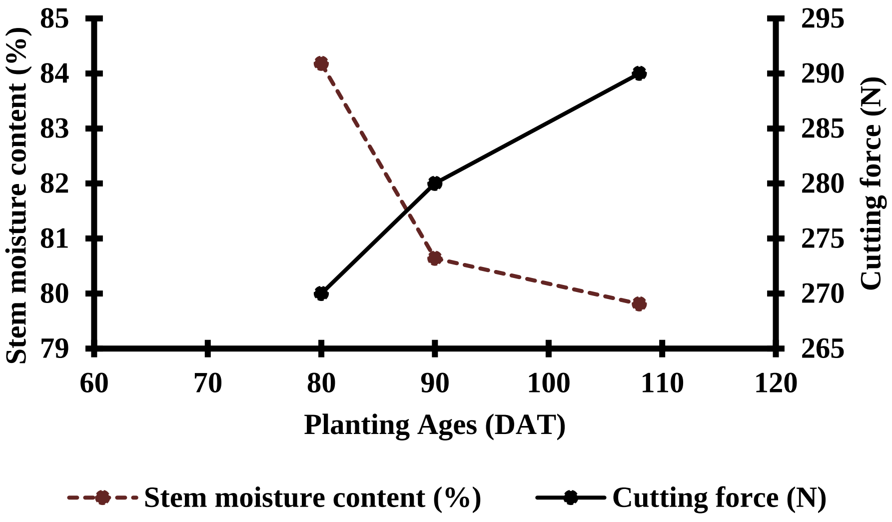

Figure 11. Stem cutting force at various seed moisture contents.

3.7. Sorghum stem cutting force

The design concept of the sorghum stalk chopping machine is based on the stem cutting force test. This parameter exhibited an overall increase as the number of DAT increases. At 80 DAT, the cutting force required to sever the stem is 270.00 N which rises to 280.00 N at 90 DAT and 290.00 N at 108 DAT. This trend indicates that as the plant matures the stems become tougher and require greater force to cut. It suggests a possible accumulation of structural components or changes in stem anatomy leading to increased resistance to cutting forces. The graph of the cutting force at various moisture contents is shown in Figure 11.

4. Conclusions and recommendation

This research examined the physical and mechanical properties of sorghum stems and seeds which are relevant to design a hold-on thresher and sorghum chopping machine. The tensile force of seed from panicles decreased significantly from 80 to 108 DAT with average values of 16.7, 11.8 and 6.0 N respectively. In addition, seed hardness increased over time from 8.2 to 44.9 N while stem hardness also increased ranging from 290.64–350 N. Furthermore, cutting force exhibits an overall increase from 270 to 290 N as DAT increased. This trend indicates that as the plant matures the stems become tougher and require greater force to cut. These parameters are relevant for the development of a thresher machine for sorghum because they affect the machine's ability to efficiently separate the grain from the rest of the plant material. The decrease in tensile force from 80 to 108 DAT may make it easier for the thresher to separate the grain from the plant material. The increase in seed hardness over time suggests that the thresher machine can use greater force without damaging the seed to effectively separate them from the rest of the plant material. This may require adjustments to the machine's design or operating parameters to ensure that it can efficiently separate the grain without damaging the seeds. The machine will need to be designed to effectively separate the grain from the rest of the plant material while minimizing damage to the stems and ensuring efficient separation of the harder seeds. Future research can explore the engineering properties of other sorghum varieties. Different varieties may exhibit variations in physical and mechanical characteristics which can influence the design and optimization of threshing and chopping machines. Comparing multiple varieties will provide a broader understanding of sorghum plants and facilitate the development of machinery suitable for diverse sorghum crops. While this study lays the foundation for designing appropriate machinery, future research should conduct long-term field trials to evaluate the performance and durability of the developed threshing and chopping machines in real-world scenarios. These trials should consider factors such as maintenance requirements, reliability and adaptability to varying field conditions. Feedback from farmers, industry stakeholders and end-users can further refine and improve the machinery.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

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