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Research Article

Development of a Cowpea Threshing Machine

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ABSTRACT

The transmission system of the thresher was developed to suit the process of threshing cowpea seeds. The developed thresher included substantial modifications to the threshing concaves, threshing fan, and threshing drum. The speed of the threshing sieve, suction, and fan were increased while the drum speed was decreased. Concave hole diameters of 20, 24, and 28 mm; drum speeds of 17, 23, and 29 m s^{-1}; and feed rates of 360, 540, and 720 kg h^{-1} were studied. Threshing efficiency, seed damage, losses of seed, and power requirements were computed. The main findings revealed that increasing the diameter of the concave holes increased threshing efficiency and seed losses while decreasing seed damage and power requirements. Increasing drum speed increases threshing efficiency, reduced seed damage, and lower power requirements while decreasing seed losses. The maximum threshing efficiency reached was 96.75%, while the seed loss was 4.25%, with a minimum seed damage of 1.18%. The power requirement was 7.38 kWh ton^{-1} at a moisture content of 14.6%. The operating costs using the developed threshing machine were decreased to 71.33 USD ha^{-1} instead of the manually threshed cowpea, which costs about 111 USD ha^{-1}.

Keywords: *Concave, Cowpea, Moisture content, Efficiency, Grain damage, Losses*

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INTRODUCTION

Cowpea is essential in securing food security needs and sustaining the balance of global food systems. The cowpea crop in Egypt faces local difficulties as a result of manual threshing. The lack of threshing machines dedicated to the cowpea crop increases harvest losses and increases the cost of production. Therefore, it is necessary to develop special machines for threshing cowpeas in Egypt. There are many ways to consume the cowpea crop, as it can be used directly as food, fodder, and fuel (Ayenan *et al.*, 2017). The chemical analysis of cowpea seeds includes carbohydrates (57.3%), fats (1.5%), fibers (8.1%), and ash (3.8%) (Arazu, 2017). There is a direct relationship between the threshing efficiency and the speed of rotation of the threshing drum. Likewise, there is an inverse relationship between the threshing efficiency, feed rate and concavity clearance of the threshing sieves. A directly proportional relationship excited between energy consumption and both drum speed and feeding rate (Timothy and Olaoye, 2013). Using relatively high speeds leads to an increase in visible grain damage of 5-10%, causing a decrease in the germination rate. Cowpea crop threshed at a standard moisture content of 6.5% (Morad *et al.*, 2007). It is preferable to operate a roller thresher for the cowpea crop at a speed of 496.0 m min^{-1} with a sieve clearance of 8.0 mm for the sieves (Asante *et al.*, 2017). Slow speeds are used when threshing cowpeas to use them as seeds, where the rolling speed does not exceed 288.5 m min^{-1} and the sieve clearance is 8.0 mm for the sieves (Onuoha *et al.*, 2022). For small-scale farmers, Dauda (2001) assessed the effectiveness of a manually operated cowpea thresher. Results indicated that threshing effectiveness was 85.9%, seed damage was 1.8%, and winnowing effectiveness was 92.35%. It is crucial to use the proper air blowing speed to remove impurities without blowing out seeds because faster cylinder speeds (700-800 rpm) cause more damage to seeds than slower rates (400-500 rpm) (Herbek and Bitzer, 2004). Moisture content, cylinder speed, feed rate, and sieve clearance all have an impact on how well cowpea seeds germinate (Ajav and Adejumo, 2005). To keep seed damage levels within the acceptable range of 1.1%, it is also necessary to select the proper drum speed (Ukatu, 2006). Harvesting the cowpea crop at a forward speed of 2.7 km h^{-1} and a seed moisture level of 12.22% is recommended. For threshing, the cowpea crop, the minimal losses, and the least consumed energy were 5.78% and 53.77 kWh ha^{-1}, respectively, at a drum speed of 19.1 m s^{-1} (500 rpm) and a seed moisture content of 9.52% (Morad *et al.*, 2007). Using a star-shaped fan blower with rotational speeds of 500–1400 rpm, the threshing efficiency was 96.29%. At a feed rate of 74.33-110.86 kg h^{-1} for threshing cowpea seeds, there is a minimum damage of 3.55%, a higher cleaning efficiency of 95.60%, and a cleaning loss of 3.71%. The star-shaped fan design is less expensive and more effective (Irtwange, 2009). When the rotating speed of the threshing drum is increased, the efficiency of threshing the cowpea crop improves. Still, the percentage of visible grain damage rises to 5%, which lowers the germination rate (Adekanye and Olaoye, 2013). The use of local threshing machines for the cowpea crop is suitable for small farmers because of the ease of maintaining and operating these machines (Oduma, 2014). Cowpea (*Vigna unguiculata* L.) was threshed at 20.7-12.6% moisture content after harvest. The threshing efficiency reached 99.40%, achieving the highest yield of 77.56 kg h^{-1} at the lowest moisture content. Cowpea beans are distinguished by their high protein content of 24.8% and carbohydrates of 63.6% (Asante *et al.*, 2017). A motorized cowpea threshing machine with a power rating of 0.75 kW, a fan speed of 826 rpm, and a beater speed of 418 rpm was developed by Samuel and Oseme (2021) to satisfy the needs of small-scale farmers in developing nations. The results demonstrated average threshing efficiency, cleaning efficiency, percentage of grain damage, throughput capacity, and successful threshing of several cowpea varieties with less grain loss. The problem with the study is that threshing the cowpea crop manually or with primitive threshing equipment increases grain loss and low germination rates, which drives up production costs and threshing time. The study was aimed at developing, modifying, and evaluating the local wheat threshing machine in order to thresh cowpea to maximize threshing efficiency, reduce grain losses, and reduce operating costs.

MATERIALS and METHODS

The field experiments were carried out at the El-Serw Agricultural Research Station, Damietta Governorate, Egypt, located at 31.24° N, 31.80° E, during 2022. A threshing machine was developed for separating dry cowpeas. The tractor specifications used in the experiment are shown in Table 1.

Table 1. *The used tractor specifications.*

Power at the PTO (factory observed at 2100 rpm)	(65 HP) universal, manufactured in Romania
Type	Diesel
Cylinders	In Line 4
Compression ratio	15.8:1
Displacement	7.6 L
Lubrication system	Fully pressure - full flow filtration
Fuel system type	Direct injection with rotary injection pump
Electrical system type	12 Volt negative ground
Gear shifting	5 forward, 1 – reverse

Thresher Description

The developed threshing machine is locally fabricated and comprises a frame loaded on two wheels, as shown in Figure 1. The threshing drum consists of a cylinder with 5 mm of thickness and 800 mm in diameter. The threshing knives are installed axially on the threshing drum with a diameter of 50 mm. The thresher machine consists partly of a threshing concave; a lower flat sieve; a fluidizer; three seed outlet hoppers; the threshing fan; a feeding hopper and a hay exit slot, were shown in Figure 1. Also, as shown in Figure 1, the threshing machine is provided with a flywheel mounted in the transmission system to adjust its balance (Figure1, No. 11).

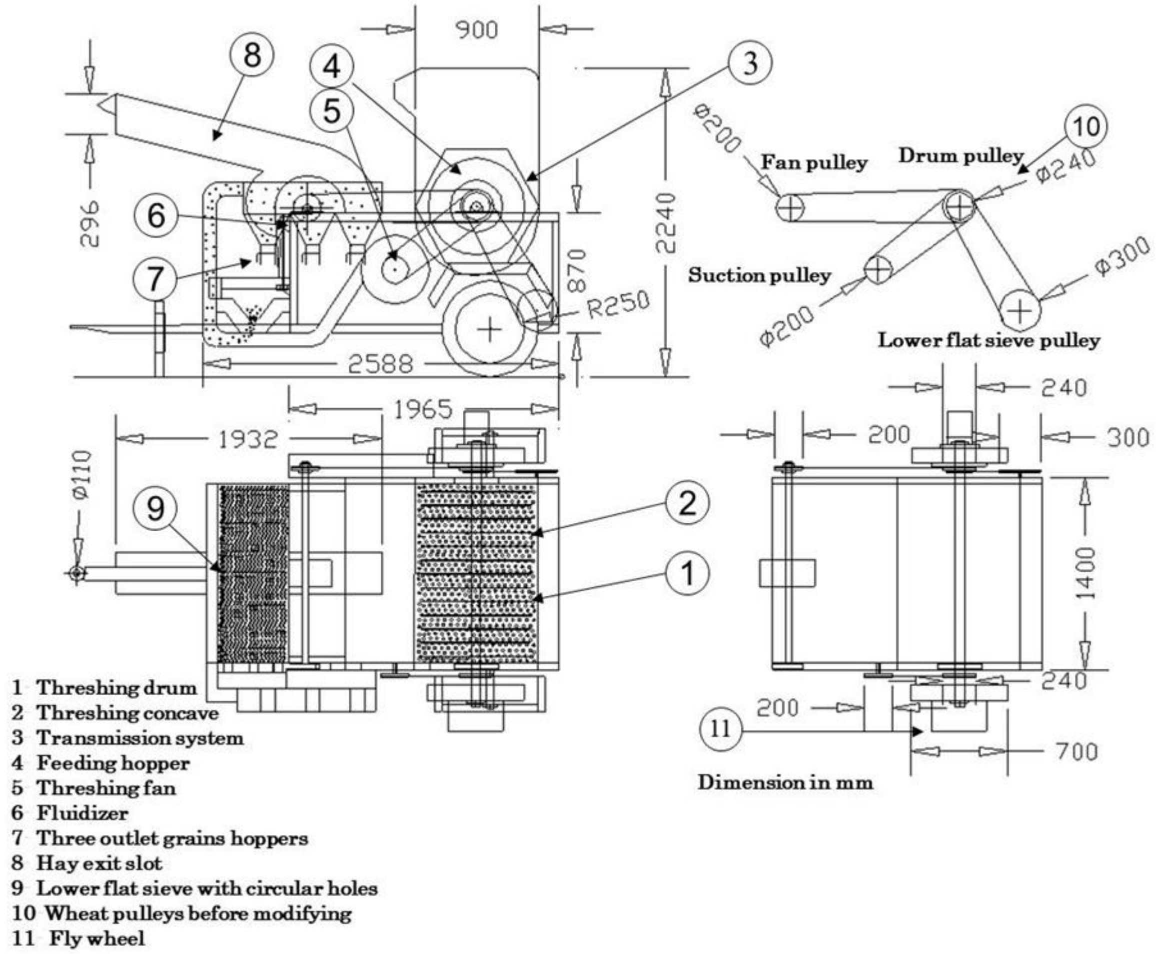

Figure 1. Threshing machine before modification.

Thresher Machine Modification

The wheat threshing machine was developed to suit the threshing and separation of dry cowpea seeds in two stages, as shown in Figures 2 and 3.

Developing Concaves

Three concaves were manufactured for threshing cowpea with hole diameters of 20, 24, and 28 mm, respectively, as shown in Figure 3. Also, the lower flat sieve was developed and fabricated with square holes of 15 × 15 mm instead of the round holes of 5 mm diameter for the wheat sieve, as shown in Figure 2, No. 9.

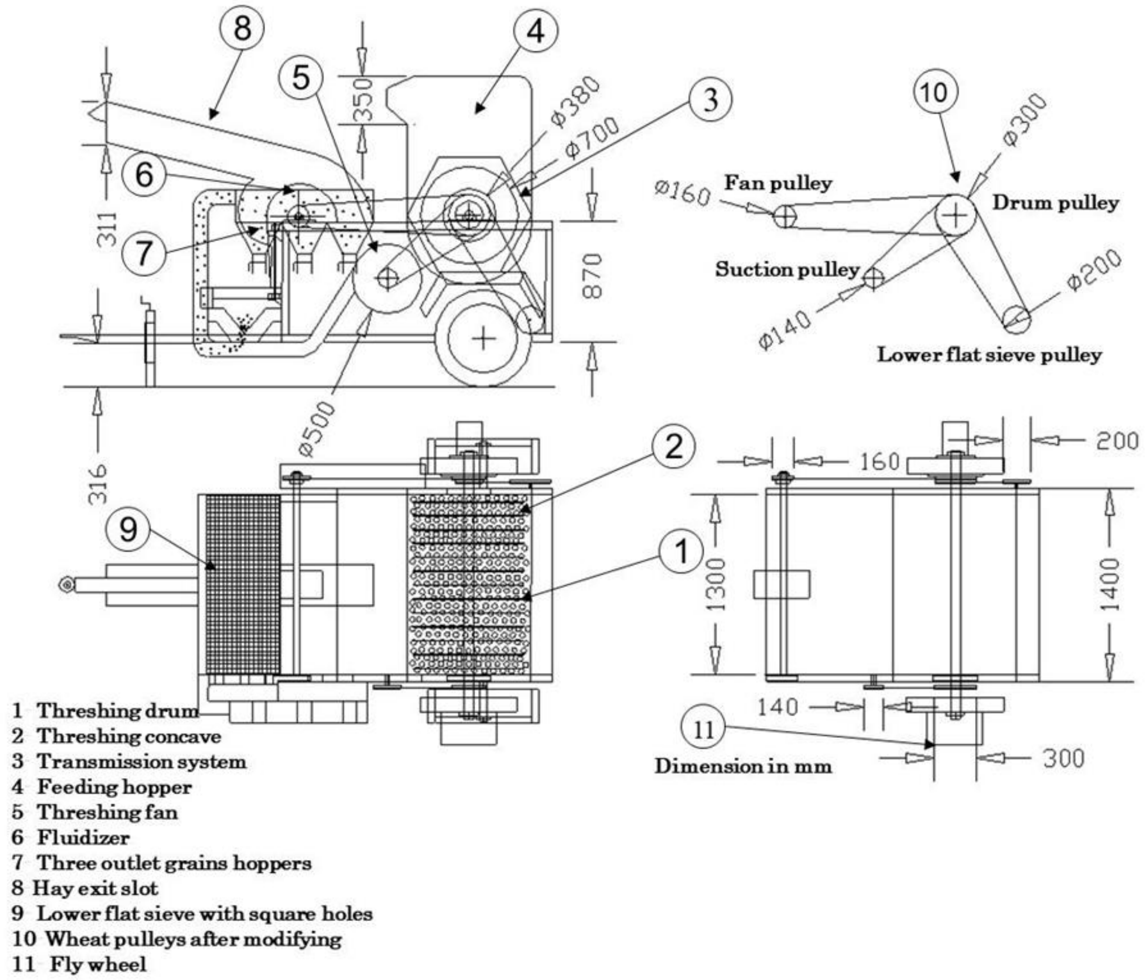

Figure 2. *Threshing machine after development.*

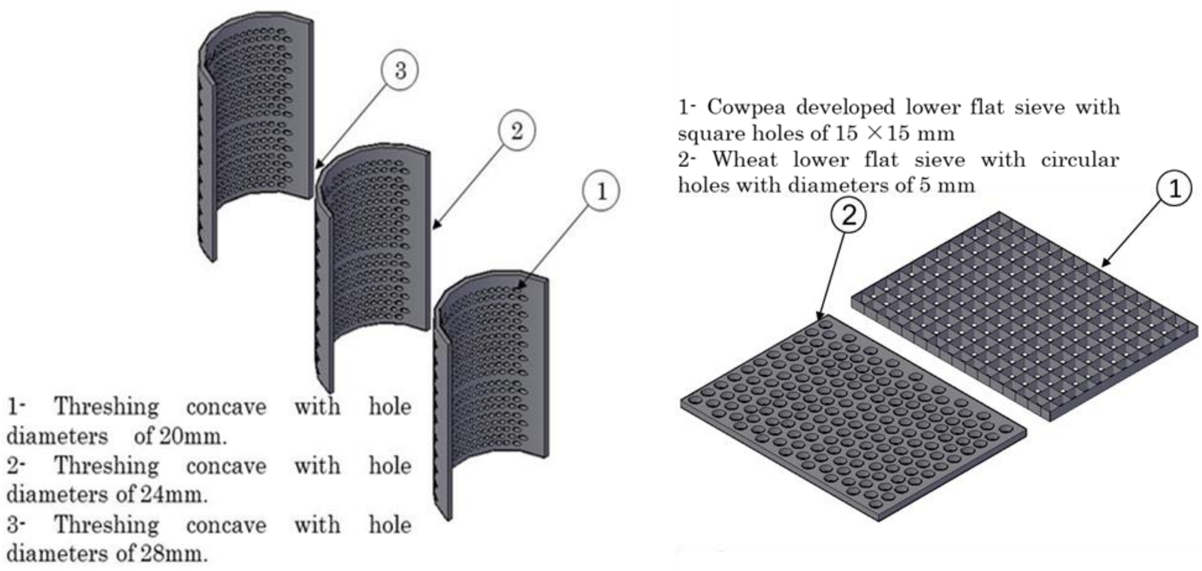

Figure 3. *Cowpea-modified concaves.*

Developing Transmission Systems

The transmission system was developed to increase the speeds of the separating concave, separating fan, and the grain suction. To lower the amount of damaged seeds, lower the rate of fuel consumption, and thus lower the cost of threshing and separating dry cowpeas, the threshing drum operates at a slower speed.

The transmission system was developed by fabricating six pulleys with different diameters suitable for threshing cowpea, as shown in the developed thresher machine in Figure 2 and Table 3. The threshing machine transmission modifications were as follows:

1. A pulley with a diameter of 300 mm was manufactured instead of the existing 200 mm pulley and fixed on the threshing drum shaft, which connected directly to the tractor-driven pulley with a wide leather belt (Figure 2).
2. A pulley with a diameter of 200 mm was fabricated and fixed on the separating sieve shaft instead of the existing wheat pulley with a diameter of 300 mm to increase the speed of the separating concave when running the threshing drum at a lower speed (Figure 2).
3. A pulley with a diameter of 300 mm was fabricated and fixed on the threshing drum shaft instead of a pulley with a diameter of 240 mm (Figure 2).
4. A pulley with a diameter of 160 mm was fabricated and fixed on the separating fan shaft instead of a pulley with a diameter of 200 mm to increase the speed of the separating fan (Figure 2).
5. A pulley with a diameter of 140 mm was fabricated and fixed on the grain extractor shaft instead of a pulley with a diameter of 200 mm to increase the speed of the grain extractor to suck out the cowpea when the threshing drum is running at a lower speed (Figure 2).

Table 2. *Transmission system speeds before and after the development.*

No.	Transmission system pulleys	Diameter, mm	Before development					
			Rotational speed			Linear speed		
			S1 rpm	S2 rpm	S3 rpm	S1 $m\ s^{-1}$	S2 $m\ s^{-1}$	S3 $m\ s^{-1}$
1	Drum pulley	200	400	550	700	4.18	5.75	7.32
2	Sieve pulley	300	267	367	467			
3	Fan pulley	200	480	660	840	5.86	8.06	10.25
4	Suction pulley	200	480	660	840			
			After development					
1	Drum pulley	300	400	550	700	6.28	8.63	10.99
2	Sieve pulley	200	600	825	1050			
3	Fan pulley	160	750	1031	1312	6.28	8.63	10.99
4	Suction pulley	140	857	1179	1500			

Where: S1-3= rotational and linear speeds.

Notice: the drum linear speeds (17, 23, and 29 $m\ s^{-1}$) were calculated according to the drum's outer diameter of 800 mm. The threshing drum is a spike-tooth drum type.

Table 3 lists the characteristics of dry cowpea, including, for example, the weight of 1000 seeds of cowpea compared to the weight of 1000 seeds of dry wheat. The cowpea's 1000 seeds weighed twice as much as 1000 seeds of dry wheat.

Table 3. *Weight of five random samples of 1000 seeds of wheat and cowpea.*

Samples	Wheat weight of 1000 seeds (g)	Cowpea weight of 1000 seeds (g)
1	850	1720
2	790	1630
3	930	1580
4	880	1520
5	950	1680

Tested Variables

Three variables were studied, as follows:

1. Three concave hole diameters (D) of 20, 24, and 28 mm, named D1, D2, and D3, respectively, were adjusted.
2. Three drum speeds (S) of 17, 23, and 29 m s^{-1}, respectively, named S1, S2, and S3, were adjusted.
3. Three feed rates (F) of 360, 540, and 720 kg h^{-1}, respectively, named F1, F2, and F3, were investigated.

Measurements

Moisture Content *(MC)*

The threshed cowpea samples were oven dried at 70°C for 72 h using a hot air oven. The samples were weighed before and after drying, and the moisture content was determined by using Equation (1) (dry basis) according to AOAC (1990).

$$MC = \frac{W_1 - W_2}{W_2} \times 100 \qquad (1)$$

Where:

MC= moisture content, %; W_1= sample weight before drying (g); W_2 = sample weight after drying (g).

Threshing Efficiency *(SE)*

The threshing efficiency of a threshing machine is its ability to separate or clear the chaff from the cowpea kernels. The threshing efficiency was measured from Equation 2 according to Ndirika (1994).

$$SE = \frac{W_A - W_B}{W_A} \times 100 \qquad (2)$$

Where:

SE= the threshing efficiency, %; W_A = total weight of the mixture of grain and chaff received at the grain outlet, kg; W_B = weight of chaff at the chaff outlet of the thresher, kg.

Seed Losses *(SL)*

The seed loss percentage through the chaff outlet is evaluated from Equation 3 according to Desta and Mishra (1990).

$$SL = \frac{W_T - W_B}{W_T} \times 100 \qquad (3)$$

Where:
SL = seed losses, %; W_B = weight of grain losses in chaff in sample, kg; W_T = total weight of the mixture (seed + chaff) in the sample, kg

Seed Damage *(SD)*
The seed damage percentage was estimated from Equation (4).

$$SD = \frac{W_{bg}}{W_T} \times 100 \quad (4)$$

Where:
SD = the percentage of seed damage, %; W_{bg} = weight of broken seeds in the sample (kg); W_T = total weight of the sample seed (kg).

Power Requirements *(PR)*
The consumed power requirements were estimated using Equation 5 according to Hunt (1983).

$$PR = F.C. \times \frac{1}{3600} \times \rho F \times L.C.V. \times 427 \times \eta_m \times \eta_{th} \times \frac{1}{75} \times \frac{1}{3.6} \times \frac{1}{P} \quad (5)$$

Where:
PR =Power consumption requirements during the threshing operation, kWh ton^{-1}; $F.C.$ = Fuel consumption L h^{-1}; ρf= Fuel density, kg L^{-1} (for solar = 0.85); $L.C.V.$ = Lower calorific value of the fuel (kcal kg^{-1}) (Solar has an average L.C.V. of 11000 kcal/kg); η_{th} = the thermal efficiency of the engine (considered to be about 35% for diesel engine); 427= Thermo-mechanical equivalent, kg m kcal^{-1}; η_m = mechanical efficiency of the engine, (considered to be 80 percent for a diesel engine); P= machine productivity, ton h^{-1}.

Statistical Analysis
The measured data for the tested factors were statistically analyzed using the Minitab program version (2019). The tests of analysis of variance (ANOVA) were done using complete randomized design (CRD), three factor model with three replications. The means of treatments were analyzed to estimate the linear regression equations at a 5% level of probability.

RESULTS AND DISCUSSION

Factors Affecting Cowpea Threshing Efficiency
As shown in Figure 4A, by increasing the concave hole diameter from D1 = 20 to D2 = 24 mm, the threshing efficiency increased from 83.23 to 87.25%. Also increasing the concave hole diameter from D2 = 24 to D3 = 28 mm, the threshing efficiency increased from 87.25 to 90.35% with drum speed (S1 = 17 m s^{-1}) and feed rate (F1 = 360 kg h^{-1}). As shown in Figure 4B, by increasing drum speed from S1 = 17 to S2 = 23 m s^{-1}, the threshing efficiency increased from 83.23 to 86.99%. Also, by increasing drum speed from S2 = 23 to S3 = 29 m s^{-1}, the threshing efficiency increased from 86.99 to 88.43% with a concave hole diameter of 20 mm at the feed rate of F1 = 360 kg h^{-1}. As shown in Figure 4C, by increasing the feed rate from

(F1 = 360 to F2 = 540 kg h^{-1}), the threshing efficiency decreased from 83.23 to 82.48%, and by increasing the feed rate from (F2 = 540 to F3 = 720 kg h^{-1}), the threshing efficiency decreased from 82.48 to 82.02% of drum speed (S1 = 17 m s^{-1}) and concave hole diameter (D1 = 20 mm).

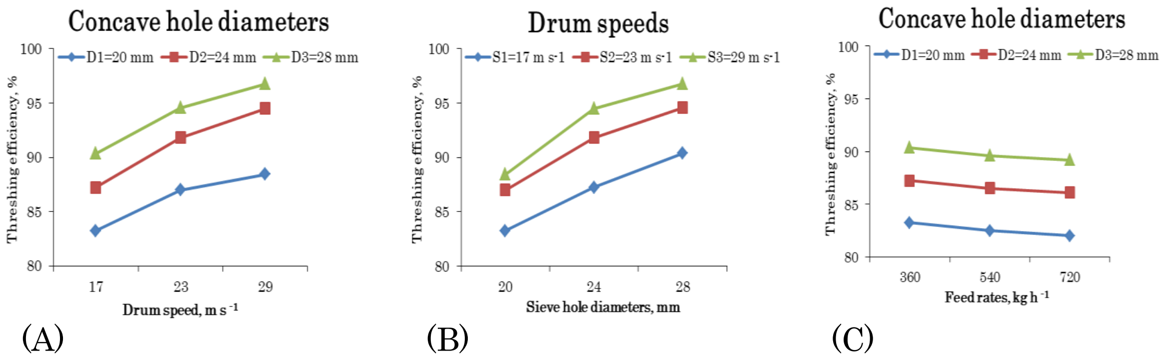

Figure 4. *(A). Effect of drum speeds on threshing efficiency at concave hole diameters; (B). Effect of concave hole diameters on threshing efficiency at drum speeds; (C). Effect of feed rates on threshing efficiency at concave hole diameters.*

The results of threshing efficiency were obtained at a moisture content of 14.6%. The obtained results of threshing efficiency may be due to the decreasing drum speed while increasing both speeds of the threshing concave and the fan, in line with the obtained results of Herbek and Bitzer (2004). Statistically, there are highly significant effects of the total interaction between different treatments ($P \leq 0.05$) for the threshing efficiency values. The regression analysis concluded that the concave hole diameter affects threshing efficiency more than drum speed and feed rate. Also, the feed rate showed less effect on threshing efficiency than drum speed, in agreement with Ukatu (2006). The effects of different parameters on threshing efficiency are arranged as follows: concave hole diameter > drum speed > feed rate. ANOVA analysis for means indicated highly significant differences between the treatments, as listed in Tables 4 and 5. The obtained regression equation for the threshing efficiency was in the form of:

SE, % = $57.818 + 0.957\ D + 0.494\ S - 0.0048\ F.$ (R^2=0.972).

[Where: Threshing efficiency *(SE, %)*, concave hole diameters *(D)*, drum speeds *(S)*, and feed rates *(F)*]

Table 4. *Means and standard errors for measurements affected by the tested factors.*

Factors		Threshing efficiency, %	Seed losses, %	Seed damage, %	Power requirements, kWh ton^{-1}
Concave hole diameters	D1	93.12±0.44^{a}	2.66±0.06^{a}	1.08±0.01^{a}	6.46±0.18^{a}
	D2	90.10±0.56^{b}	3.22±0.08^{b}	1.00±0.01^{b}	5.90±0.12^{b}
	D3	85.47±0.51^{c}	3.59±0.08^{c}	0.91±0.01^{c}	5.36±0.08^{c}
	P value	0.0001	0.0001	0.0001	0.0001
Drum speeds	S1	92.24±0.58^{a}	3.47±0.11^{a}	0.95±0.02^{a}	5.33±0.07^{a}
	S2	90.15±0.65^{b}	3.17±0.09^{b}	0.99±0.02^{b}	5.88±0.11^{b}
	S3	86.31±0.68^{c}	2.83±0.08^{c}	1.04±0.02^{c}	6.52±0.18^{c}
	P value	0.0001	0.0001	0.0001	0.0001
Feed rates	F1	90.43±0.81^{a}	2.78±0.09^{a}	1.05±0.02^{a}	5.46±0.09^{a}
	F2	89.58±0.79^{b}	3.22±0.09^{b}	0.99±0.01^{b}	5.84±0.13^{b}
	F3	88.69±0.76^{c}	3.46±0.09^{c}	0.94±0.02^{c}	6.43±0.18^{c}
	P value	0.0001	0.0001	0.0001	0.0001

$^{a-b}$ the means with no common subscript within each column differed significantly ($P \leq 0.05$)

Table 5. *ANOVA analysis for measurements.*

Measurement	Source	Degree of freedom	Adj (ss)	Mean Square (MS)	F value	Probability
Threshing efficiency	Concave holes diameter	1	791.89	791.891	1642.53	0.0001***
	Drum speed	1	475.62	475.616	986.51	0.0001***
	Feed rate	1	40.77	40.768	84.56	0.0001***
	Error	77	37.12	0.482		
	Total	80	25.375			
Seed losses	Concave holes diameter	1	11.5371	11.5371	789.41	0.0001***
	Drum speed	1	5.4722	5.4722	374.43	0.0001***
	Feed rate	1	6.2424	6.2424	427.13	0.0001***
	Error	77	1.1253	0.0146		
	Total	80	24.3770			
Seed damage	Concave holes diameter	1	0.375	0.375	1879.07	0.0001***
	Drum speed	1	0.104017	0.104017	521.21	0.0001***
	Feed rate	1	0.156817	0.156817	785.78	0.0001***
	Error	77	0.015367	0.000200		
	Total	80	0.651200			
Power requirements	Concave holes diameter	1	74.202	74.2017	257.36	0.0001***
	Drum speed	1	77.760	77.7600	269.70	0.0001***
	Feed rate	1	51.627	51.6267	179.06	0.0001***
	Error	77	22.201	0.2883		
	Total	80	225.789			

The significance probability at ($P \leq 0.05$)

Factors Affecting Cowpea Seed Losses

As shown in Figure 5A, increasing the diameter of the concave holes from (D1= 20 to D2= 24 mm) increased seed losses from 2.4 to 3.1% when increasing the diameter of the concave holes from (D2= 24 to D3= 28 mm). Also, seed losses increased from 3.1 to 3.7% under drum speed (S1 = 17 m s^{-1}) and feed rate (F1 = 360 kg h^{-1}). As shown in Figure 5B, with increasing drum speed from S1 = 17 to S2 = 23 m s^{-1}, seed losses decreased from 2.4 to 2.3% with increasing drum speed from S2 = 23 to S3 = 29 m s^{-1}. Also, seed losses decreased from 2.3 to 2.2% at concave hole diameter (D1 = 20 mm) with feed rate (F1 = 360 kg h^{-1}). As shown in Figure 5C, with an increase in feed rate from (F1 = 360 to F2 = 540 kg h^{-1}), the losses of seed increased from 2.4 to 2.96% at an increase in feed rate from (F2 = 540 to F3 = 720 kg h^{-1}). Also, seed losses increased from 2.96 to 3.15% under drum speed (S1 = 17 m s^{-1}) with a concave hole diameter (D1 = 20 mm).

The results of cowpea seed losses were obtained at a moisture content of 14.6%. These results were due to using an appropriate drum rotation speed that led to a significant decrease in seed losses, as agreed upon by Adekanye and Olaoye (2013); Oduma (2014). Statistically, there are highly significant effects of the total interaction between different treatments ($P \leq 0.05$) for the seed loss values. The regression analysis concluded that the concave hole diameter affects seed losses more than feed rate and drum speed. Also, drum speed showed less effect on seed losses than feed rate. The effects of different parameters on seed losses were arranged as follows: concave hole diameter > feed rate > drum speed. ANOVA analysis indicated highly significant differences between the treatments listed in Tables 4 and 5. The obtained regression equation for seed losses was in the form of:

$$\textbf{SL, \%} = 0.583 + 0.116\,D - 0.0531S + 0.0019\,F. \quad (R^2=0.954).$$

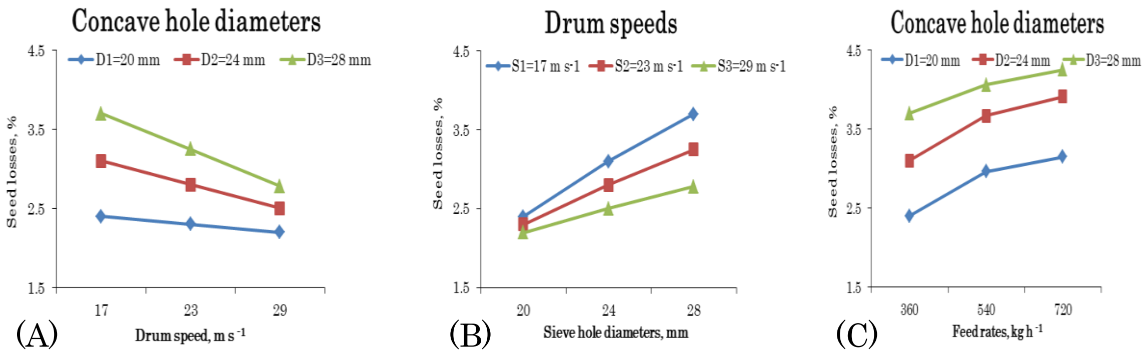

Figure 5. *(A) Effect of drum speeds on seed losses at concave hole diameters; (B). Effect of concave hole diameters on seed losses at drum speeds; (C) Effect of feed rates on seed losses at concave hole diameters.*

Factors Affecting Cowpea Seed Damage

As shown in Figure 6A, seed damage was reduced from 1.1 to 1.0% by increasing the diameter of the concave holes from (D1= 20 to D2= 24 mm) to (D2= 24 to D3= 28 mm). Furthermore, seed damage decreased from 1.0 to 0.94% as drum speed (S1= 17 m s^{-1}) increased and feed rate (F1= 360 kg h^{-1}) decreased. As shown in Figure 6B, with increasing drum speed from (S1 = 17 to S2 = 23 m s^{-1}), the seed damage increased from 1.1 to 1.15% with increasing drum speed from (S2 = 23 to S3 = 29 m s^{-1}). Whereas the seed damage increased from 1.15 to 1.18% under concave hole diameter (D1 = 20 mm) with feed rate (F1 = 360 kg h^{-1}). As shown in Figure 6C, increasing the feed rate from (F1= 360 to F2= 540 kg h^{-1}) reduced seed damage from 1.1 to 1.03% when the feed rate was increased from (F2= 360 to F3= 720 kg h^{-1}). Furthermore, with the smallest drum speed (S1= 17 m s^{-1}) and concave hole diameter (D1= 20 mm), seed damage decreased from 1.03 to 0.95%.

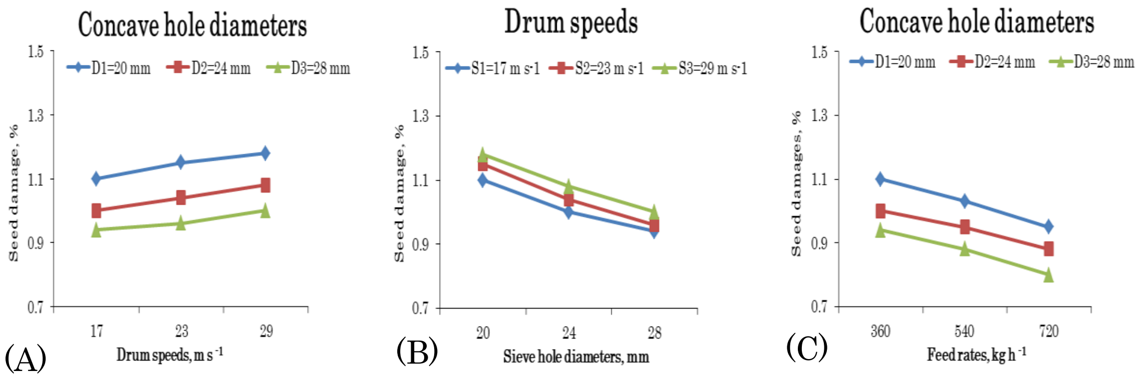

Figure 6. *(A) Effect of drum speeds on seed damage at concave hole diameters; (B)Effect of concave hole diameters on seed damage at drum speeds (C) Effect of feed rates on seed damage at concave hole diameters.*

The results of seed damage were obtained at a moisture content of 14.6%. The results of seed damage were relatively decreased using an appropriate drum rotational speed with an appropriate air fan speed and modifying concaves, in agreement with Ajav and Adejumo (2005); Morad *et al.*, (2007). Statistically, there are highly significant effects of the total interaction between different treatments ($P \leq 0.05$) for the seed damage values. The regression analysis concluded that the concave hole diameter affects seed damage more significantly than feed rate or drum speed. Furthermore, drum speed had the least effect on seed damage when compared to feed rate. The following parameters affected by seed damage: concave hole diameter > feed rate > drum speed. ANOVA analysis indicated highly significant differences between the treatments listed in Tables 4 and 5. The obtained regression equation was in the form of:

SD, % = 1.489 - 0.021 D + 0.0073 S - 0.000299 F. (R^2=0.976).

Factors Affecting Power Requirements

As shown in Figure 7A, by increasing the concave hole diameter from D1 = 20 to D2 = 24 mm, the power requirements decreased from 5.67 to 5.35 kWh ton^{-1}. Also increasing the concave hole diameter from D2 = 24 to D3 = 28 mm, the power requirements decreased from 5.35 to 4.97 kWh ton^{-1} under drum speed (S1 = 17 m s^{-1}) with feed rate (F1 = 360 kg h^{-1}). As shown in Figure 7B, by increasing the drum speed from S1 = 17 to S2 = 23 m s^{-1}, the power requirements increased from 5.67 to 6.33 kWh ton^{-1}. In addition, the power requirements increased from 6.33 to 7.38 kWh ton^{-1} as the drum speed increased from (S2= 23 to S3= 29 m s^{-1}) with a concave hole diameter (D1= 20 mm) and feed rate (F1= 360 kg h^{-1}). As shown in Figure 7C, with an increasing feed rate from (F1 = 360 to F2 = 540 kg h^{-1}), the power requirements increased from 5.88 to 6.30 kWh ton^{-1}. Also, by increasing the feed rate from F2 = 540 to F3 = 720 kg h^{-1}, the power requirements decreased from 6.30 to 7.20 kWh ton^{-1} at drum speed (S1 = 17 m s^{-1}) with a 20 mm concave hole diameter.

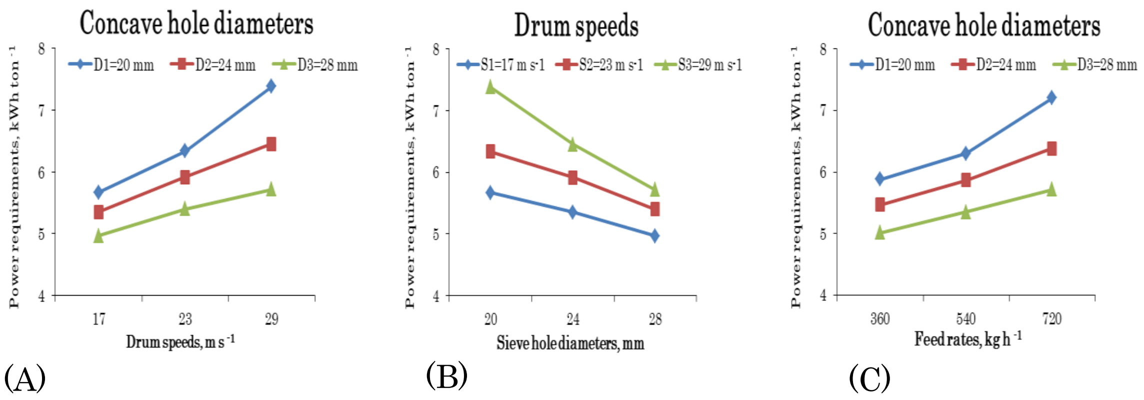

Figure 7. *(A). Effect of drum speeds on the power requirements at concave hole diameters; (B)Effect of concave hole diameters on the power requirements at drum speeds; (C) Effect of feed rates on the power requirements at concave hole diameters.*

The power requirements results were obtained at a moisture content of 14.6%. The consumed power results were due to using appropriate air fan plowing and appropriate concaves and spike tooth drum type rotational speeds while adjusting the transmission system, which led to a decrease in fuel consumption and, thus, a decrease in consumed power, in agreement with Irtwange, (2009); Samuel and Oseme (2021); Onuoha *et al.* (2022). Statistically, there are highly significant effects of the total interaction between different treatments ($P \leq 0.05$) for the power requirement values. The regression analysis concluded that drum speed consumed more power than the concave hole diameter or feed rate. While the feed rate showed less effect on power requirements than the concave hole diameter, the following parameters affected power requirements: speed > concave holes diameter drum > feed rate. ANOVA analysis indicated highly significant differences between the treatments listed in Tables 4 and 5. The obtained regression equation for power requirements was in the form of:

PR, kWh ton^{-1} = $5.464 - 0.138\,D + 0.0991\,S + 0.0027F$. ($R^2$=0.885).

CONCLUSION

The highest value of cowpea threshing efficiency was obtained, and it was 96.75% at a concave opening of 28 mm, and the maximum speed of the roller was 29 m s^{-1}. The lowest percentage of grain losses was 2.2% when using a concave hole diameter of 20 mm at the lowest feed rate of 360 kg h^{-1} and the lowest drum speed of 17 m s^{-1}. The lowest value of seed damage percentage was 4.97% when using a concave with 28 mm holes, and the lowest drum speed was 17 m s^{-1}. The highest level of energy consumption was 7.38 kWh ton^{-1} at the minimum concave holes of 20 mm, with a maximum drum speed of 29 m s^{-1} and a maximum feed rate of 720 kg h^{-1}. It could be recommended to utilize the wheat threshing machine development process to adapt it to threshing the cowpea crop.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mohamed Mansour Shalaby Refaay designed the concept of entire project. The investigation, methodology and writing of the original draft were done by him, read and approved the final manuscript.
Ahmed Shawky El-Sayed was involved in the methodology and former analysis of the experiment. He carried out the review and editing of the original drafted copy, read and approved the final manuscript.
Mokhtar Cottb Ahmed Awad participated in the designed and investigation of the experiment. He also handled the data curative and validation, read and approved the final manuscript.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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