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RESEARCH TITLE

The Effect of Selected Mechanical Threshing Parameters on Kernel Damage and Threshability of Wheat Through Developing A Local Made Thresher for Small-Scale Farmers

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Abstract

This study aimed to design, fabricate, and evaluate a locally made wheat thresher suitable for small-scale farmers under local operating conditions in Northern State, Sudan. The machine was developed to provide a simple, low-cost, and efficient threshing system capable of improving wheat threshing performance while reducing post-harvest losses. The main components of the prototype included a threshing cylinder, concave, shaker, pulleys, cleaning fan, sieve unit, and clean grain outlet. The performance of the thresher was evaluated using Imam wheat variety under different mechanical operating parameters: two cylinder speeds of 650 and 900 rpm, two fan speeds of 1042 and 1390 rpm, two concave–cylinder clearances of 15 and 20 mm, and two threshing cylinder types, namely rasp-bar and wire-loop cylinders. The experiment was arranged in a randomized complete block design with three replications, and the measured indicators included threshed grains, un-threshed grains, broken grains, separation losses, cleaning efficiency, and product purity. The results revealed highly significant differences among treatments at **$P \leq 0.01$**. The best overall performance was obtained at a cylinder speed of **900 rpm**, fan speed of **1390 rpm**, concave–cylinder clearance of **20 mm**, and using the **rasp-bar cylinder**. Under these conditions, the machine achieved a threshing efficiency of **69.9%**, separation losses of **30.1%**, cleaning efficiency of **82.3%**, and product purity of **93.2%**. The findings also showed that increasing cylinder speed, fan speed, and concave clearance improved threshing and cleaning performance, although higher operating intensity was associated with increased grain damage and grain losses mixed with chaff and stems. The study concludes that the developed wheat thresher can enhance threshing operations for small-scale farmers by providing acceptable threshing efficiency, improved cleaning quality, and high product purity, while emphasizing the need to balance operating speed and clearance settings to minimize kernel damage.

Key Words: Wheat thresher; small-scale farmers; threshing efficiency; separation losses; cleaning efficiency; product purity.

عنوان البحث

أثر بعض معاملات الدِّراس الميكانيكي المختارة في تلف حبوب القمح وقابلية الدِّراس من خلال تطوير آلة دَرّاسة قمح محلية الصنع لصغار المزارعين

المستخلص

هدفت هذه الدراسة إلى تصميم وتصنيع وتقييم **آلة دَرّاسة قمح** محلية الصنع ملائمة لصغار المزارعين في ظل ظروف التشغيل المحلية بالولاية الشمالية في السودان. وقد طُوِّرت الآلة لتوفير نظام دِراس بسيط ومنخفض التكلفة وفعّال، قادر على تحسين أداء دِراس القمح وتقليل الفاقد بعد الحصاد. وتكوّن النموذج الأولي للآلة من أسطوانة الدِّراس، والكونكيف، والهزاز، والبكرات، ومروحة التنظيف، ووحدة الغربال، ومخرج الحبوب النظيفة. جرى تقييم أداء **آلة الدَّرّاسة** باستخدام صنف القمح إمام تحت معاملات تشغيل ميكانيكية مختلفة، شملت سرعتين لأسطوانة الدِّراس هما 650 و900 دورة/دقيقة، وسرعتين للمروحة هما 1042 و1390 دورة/دقيقة، ومسافتين للخلوص بين الأسطوانة والكونكيف هما 15 و20 ملم، ونوعين من أسطوانات الدِّراس هما الأسطوانة ذات القضبان المسننة والأسطوانة ذات الحلقات السلكية. نُفذت التجربة وفق تصميم القطاعات العشوائية الكاملة بثلاث مكررات، وشملت مؤشرات القياس كمية الحبوب المدروسة، والحبوب غير المدروسة، والحبوب المكسورة، وفواقد الفصل، وكفاءة التنظيف، ونقاوة المنتج. أظهرت النتائج وجود فروق عالية المعنوية بين المعاملات عند مستوى $P \leq 0.01$. وقد تحقق أفضل أداء كلي عند سرعة أسطوانة مقدارها **900 دورة/دقيقة**، وسرعة مروحة مقدارها **1390دورة/دقيقة**، وخلوص بين الأسطوانة والكونكيف قدره **20ملم**، وباستخدام الأسطوانة ذات القضبان المسننة. وفي ظل هذه الظروف، حققت **آلة الدَّرّاسة** كفاءة دِراس بلغت **69.9%**، وفواقد فصل بلغت **30.1%**، وكفاءة تنظيف بلغت **82.3%**، ونقاوة منتج بلغت **93.2%**. كما أوضحت النتائج أن زيادة سرعة الأسطوانة وسرعة المروحة وخلوص الكونكيف أدت إلى تحسين أداء الدِّراس والتنظيف، إلا أن زيادة شدة التشغيل ارتبطت بارتفاع تلف الحبوب وزيادة الفواقد المختلطة بالقش والسيقان. وتخلص الدراسة إلى أن **آلة دَرّاسة القمح** المطوّرة يمكن أن تسهم في تحسين عمليات الدِّراس لدى صغار المزارعين من خلال توفير كفاءة دِراس مقبولة، وجودة تنظيف محسنة، ونقاوة عالية للمنتج، مع التأكيد على ضرورة تحقيق توازن مناسب بين سرعة التشغيل وإعدادات الخلوص للحد من تلف الحبوب.

الكلمات المفتاحية: آلة دَرّاسة القمح؛ صغار المزارعين؛ كفاءة الدِّراس؛ فواقد الفصل؛ كفاءة التنظيف؛ نقاوة المنتج.

1. Introduction:

In Sudan, wheat production is mainly carried out under irrigated farming systems, and since the 1980s it has been considered a key crop for food security (El Faki, 2000). Although wheat occupies only about 3% of the total cereal cultivation area, it contributes approximately 11.7% of overall cereal production during the period 2006-2009 (MoFEP, 2012). In contrast, other major cereals such as sorghum and millet are largely cultivated under rain-fed conditions. The principal wheat-growing regions include the Gezira and New Halfa schemes, as well as Northern, River Nile, and White Nile states.

Wheat productivity in Sudan is generally low and unstable (Saad, 2010). This low performance is attributed not only to heat stress but also to several agronomic and management constraints, including delayed sowing, limited access to improved inputs such as quality seed, inefficient fertilizer application, weed infestation, inadequate irrigation water, and late harvesting. In addition, weak agricultural extension services have contributed to farmers' limited awareness of modern production technologies (Kabesh et al., 2009).

In the Northern State, wheat harvesting represents one of the most labor-intensive and costly field operations, accounting for about 20% of total variable production costs, second only to irrigation costs at 31.5% (Fageeri, 2005). The traditional harvesting method involves manual cutting with sickles, bundling the crop, stacking it in heaps, and subsequently threshing it using stationary threshers.

Although various grain processing machines have been developed worldwide for threshing operations, most of them are expensive and require high power inputs, making them unsuitable for small-scale farmers. Therefore, there is a clear need to design, fabricate, and evaluate a wheat threshing machine that is portable, cost-effective, and capable of operating using either an electric motor or a diesel engine, particularly for use in rural farming areas.

2. Literature reviews:

Effective design of agricultural machinery and post-harvest operations for harvesting, handling, storing, and processing agricultural products into food and feed depends greatly on a clear understanding of the physical characteristics of these materials. According to Strivastava et al. (1990), the grain separation process is highly affected by changes in the physical properties of grain, straw, and chaff. Several studies have reported that machine parameters such as fan speed, cylinder speed, and concave clearance play major roles in determining the threshing efficiency of mechanical threshers (Singh et al., 1981; Joshi et al., 1981; Ghaly, 1985; Behera et al., 1990).

Ponican et al. (2009) examined threshing mechanism parameters for maize and found that peripheral speed, together with the clearance between the cylinder and concave, was among the most significant factors influencing crop quality. Sarwar and Khan (1987) evaluated the performance of rasp-bar and wire-loop cylinders in rice threshing operations. Their findings indicated that the rasp-bar cylinder produced a higher percentage of husked grains compared with the wire-loop cylinder at all tested peripheral speeds. Likewise, Addo et al. (2004) observed that the rasp-bar drum provides a larger surface area for frictional impact during threshing.

Concave design has also been shown to influence grain separation. Arnold (1964) found that increasing the concave length improved grain separation through the concave. Similarly, Cooper (1978) investigated the influence of concave length during wheat and barley threshing and reported that increasing the concave arc from 84° to 105° enhanced grain separation by approximately 17%.

Several researchers have examined the influence of cylinder speed on threshing efficiency and grain losses. Singh and Kumar (1976) reported that higher cylinder speeds reduced the percentage of un-threshed seeds. In the development of a power-operated paddy thresher, Dash and Das (1989) recommended using high cylinder peripheral velocity to minimize un-threshed losses. Abo El-Khair (1991) likewise concluded that increasing drum speed reduced un-threshed seed losses. Furthermore, El-Haddad (2004) developed a chopping, threshing, and winnowing machine suitable for recycling crop residues, and the experimental results demonstrated that un-threshed grain losses decreased with increasing cylinder speed.

Despite the positive effect of increased cylinder speed on threshing performance, excessive speed may increase grain damage. Kolganov (1956) stated that excessive cylinder speeds lead to seed damage during threshing operations. Similarly, Vas and Harison (1969) identified cylinder speed as a major factor influencing grain damage in wheat threshing. Singh and Kumar (1976) also reported that grain damage increased with increasing cylinder speed.

Kumar and Goss (1979) analyzed data from 224 field experiments to develop models describing combine harvester performance. Their model for broken seeds revealed a significant relationship between cylinder speed and seed breakage, where increasing cylinder speed from 20 to 25 m s^{-1} raised the percentage of broken seeds from 6% to 9%. Joshi and Singh (1980), during the development of the Pantnagar IRRI multi-crop thresher, observed that higher cylinder speeds reduced cylinder losses but simultaneously increased visible grain damage at all cylinder-concave clearances. Sharma and Devnani (1980) further reported that visible grain damage reached about 5% at higher operating speeds.

Other studies confirmed the relationship between machine speed and grain damage across different crops. Singh et al. (1981) investigated the effects of crop and machine parameters on threshing effectiveness and soybean seed quality, and found that external grain damage, determined from the weight of broken grains in collected samples, increased as cylinder speed increased. Likewise, Anwar and Gopta (1990) found that grain damage percentage increased with higher drum speed under all feed rates and concave settings. Alonge and Adegbulugbe (2000) also confirmed that kernel damage rises with increasing machine speed. Similar observations were reported by Sudajan et al. (2002), who stated that visible grain damage increased as drum speed increased.

Johnson (2003) recommended operating threshers at the minimum cylinder speed capable of achieving efficient threshing while maintaining acceptable grain damage levels. Khazaei et al. (2003) evaluated the influence of drum speed on damaged grains and threshed pods in a finger-type chickpea thresher and concluded that drum speed had the greatest effect on damage intensity. El-Haddad (2004), in developing a chopping, threshing, and winnowing machine for crop residue recycling, also observed that visible grain damage increased with increasing cylinder speed.

Further evidence was provided by Vejasit and Salokhe (2004), who studied the machine and crop parameters of an axial-flow soybean thresher and reported that threshing drum speed significantly influenced grain damage. Askari Asli-Ardeh et al. (2008), while evaluating a power tiller-operated small thresher, concluded that grain damage increased as peripheral speed increased. Chimchana et al. (2008) developed an unequal-speed co-axial split-rotor rice thresher and determined that the optimum threshing rotor speed was approximately 600 rpm, whereas speeds exceeding 800 rpm caused increased grain damage. In addition, Ponican et al. (2009) investigated maize threshing parameters using a tangential threshing mechanism and found that increasing cylinder peripheral speed from 9.4 to 21.4 m s^{-1} increased grain damage from 3.8% to 6.01%.

On the other hand, many studies have emphasized the role of cylinder speed in improving threshing efficiency. Singh and Kumar (1976) reported that threshing efficiency improved with increasing cylinder tip speed. Likewise, Ige (1978), while evaluating the threshing and separation performance of a locally manufactured cowpea thresher, found that drum speed had a significant effect on cowpea threshing efficiency. Sharma and Devnani (1980) also observed that higher cylinder speeds resulted in improved threshing efficiency.

Similarly, Desta and Mishra (1990), during the development and performance evaluation of a sorghum thresher, reported that threshing efficiency increased with increasing cylinder speed under all feed rates and cylinder-concave clearances. Hadad (2000) stated that threshing efficiency increased as drum speed increased and feed rate decreased. Simonyan and Oni (2001) likewise confirmed that cylinder speed significantly influenced threshing effectiveness. El-Haddad (2004), in designing and manufacturing a chopping, threshing, and winnowing machine suitable for recycling crop residues, found experimentally that threshing efficiency increased with increasing cylinder speed.

In addition, Vejasit and Salokhe (2004) studied the machine-crop parameters of an axial-flow soybean thresher and concluded that threshing drum speed had a significant effect on soybean threshing efficiency. According to Adewumi et al. (2007), performance evaluation results showed that threshing efficiency increased with increasing cylinder speed, with efficiency values ranging from 54.5% to 100%. Radwan et al. (2009) conducted experiments on the developed El-Shams tangential axial-flow cereal thresher and reported that increasing rotor speed improved threshing efficiency. At an air speed of 4.8 m s^{-1} and grain moisture content of 10.36%, increasing rotor speed from 500 to 700 rpm increased threshing efficiency from 70.2% to 73.7%.

Furthermore, Joshi and Singh (1980), during the development of the Pantnagar IRRI multi-crop thresher, observed that the cleaning efficiency of the thresher improved as cylinder speed increased. Thus, the literature indicates that cylinder speed, fan speed, concave clearance, and cylinder type are critical parameters affecting threshing efficiency, cleaning efficiency, grain losses, and kernel damage. Therefore, selecting suitable operating conditions is essential to achieve a balance between high threshing performance and reduced grain damage.

3. Materials and methods:

3.1. Design analysis:

The design analysis was carried out with a view to evaluate the necessary design parameters, strength and size of materials for consideration in the selection of the various machine parts in order to avoid failure by excessive yielding and fatigue during the required working life of the machine.

3.1.1. Determination of the threshing drum diameter:

The threshing drum diameter is needed in order to determine the capacity of the threshing drum. Therefore, the diameter of the threshing drum was determined using the standard formula for calculating the volume of a cylinder and is given as follows:

$$V = \frac{\pi d^2}{4} \times L \qquad (1)$$

$$d = \sqrt{\frac{4 \times V}{\pi L}} \qquad (2)$$

Where;

V = the volume of the drum (m).

d = the diameter of the cylinder (m).

L = the length of the cylinder (m).

3.1.1.1. Evaluation of weight of threshing drum:

The weight of the threshing drum was determined in order to know the amount of load being exerted on the shaft by the threshing drum. Therefore the weight of the threshing drum is expressed as:

$W = Mg$……………………….…….….…………………………(3)

$M = \rho V$…………………………….………….……..…………(4)

Where;

W = the weight of threshing drum (N).

M = mass of threshing drum (kg).

g = acceleration due to gravity (m/s^2).

ρ = the density of the drum (kg/m^3).

V = the volume of the cylinder (m^3).

3.1.1.2. Power required to thresh grain from the panicle:

The power required to thresh grains from the wheat panicles is expressed as:

$P = T\omega$………………………...………...……………..………(5)

$\omega = \frac{2\pi N}{60}$……………………………….…………………..…….(6)

$T = Fr$…………………………...…...……….………...………..….(7)

Where;

P is the power required (watts).

T = torque of the drum (Nm).

ω = angular velocity (rad/s).

N = speed of the threshing drum in rpm/min.

F = the impact force required to thresh wheat.

ri = the distance of point of force application from axis of rotation (m).

(Ndirika, 1997; Abu, 2006).

The torque resulting from individual force is given by;

$T = Fi \times ri$…………..………………..……………………………(8)

Where Fi and ri are force and radius respectively.

Total torque (T) on the drum is calculated as follows:

$T = T_R \times K_B$………………………...……………..…………..…..(9)

Where, K_B is the number of beaters on the drum.

3.1.2. Design of the pulley and belt:

The nominal pitch length of the motor to threshing drum belt was determined in order to know the actual belt size that is needed to transfer power from the electric motor to the threshing drum. Therefore, according to Gupta and Khurmi (2005), the nominal pitch length (L) is given as follows:

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \left[\frac{(D_2 - D_1)^2}{4C}\right] \ldots\ldots (10)$$

Where;

D_1 = diameter of the motor pulley (m).

D_2 = diameter of the threshing drum pulley (m).

C = the center distance between the motor pulley and the threshing drum shaft pulley, which is expressed as:

$$C = \left(\frac{D_2 + D_1}{2}\right) + D_1 \ldots\ldots (11)$$

3.1.2.1. Determination of angle of contact of the belt between the shaker pulley and the fan pulley:

The angle of contact of belt between the shaker pulley and the fan pulley was determined in order to know the tensions which exist between the belt and the pulleys. Therefore, the angle of lap of the belt between the two pulleys was calculated from the expression below:

$$\theta = (180 - 2\alpha) \times \frac{\pi}{180} \text{rad} \ldots\ldots (12)$$

Such that, $\alpha = \sin^{-1}\left(\frac{r_4 - r_3}{C}\right)$

Where;

Ө = angle of contact of belt between the pulleys.

r_4 = radius of the fan pulley (mm).

3.1.3. Evaluation of the tension in shaker-belt:

The tension of the belt is determined so as to ascertain the power transmitted by the shaker to fan belt, therefore the tension on the two sides of the open belt was calculated as shown below:

$$\frac{T_1}{T_2} = e^{K\theta} (\text{Gupta and Khurmi, 2005}) \ldots\ldots (13)$$

Where;

T_1= the tension of the belt on the tight side.

T_2 = the tension of the belt on the slack side.

K = the coefficient of friction between the belt and the pulley.

Ө = the angle of contact or lap of belt between the two pulleys = 3.10 rad.

The power transmitted by an open belt is given by;

$$P = (T_1 - T_2)V \ldots\ldots (14)$$

Where;

V = the velocity of the belt (m/s).

P = the power transmitted by belt (watts).

3.1.4. Shaft design:

3.1.4.1. Determination of threshing drum shaft diameter:

This was determined to know the shaft diameter that can withstand the applied loads. For a solid shaft with little or no axial load, the diameter of the shaft was determined using:

$$d^3 = \frac{16}{\pi s_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \ldots\ldots\ldots\ldots\ldots\ldots(15)$$

Where;

d = the diameter of the shaft.

S_S = the allowable stress= $40\times10^6 \mathrm{Nm}^{-1}$.

K_b = the combine shock and fatigue factor applied to bending moment.

M_b = the bending moment (Nm).

K_t = the combine shock and fatigue factor applied to torsional moment.

M_t = the torsional moment (Nm).

(Hall *et al.,* 1980).

3.1.5. Determination of angle of twist:

The angle of twist helps to know whether the diameter of the shaft is safe to carry the applied load. According to Hall *et al.,* (1980), the amount of twist permissible depends on the type of load application and varies about 0.3 degree per meter for a machine tool shaft and about 3 degrees per meter for line shafting. Therefore, angle of twist (θ); for solid shaft is given as follow:

$$\theta = \frac{584 M_t L}{G d^4} \ldots\ldots\ldots\ldots\ldots\ldots(16)$$

Where;

L = the length of shaft (m).

M_t = the torsional moment (Nm).

G = the torsional modulus (Nm^2).

d = the diameter of the shaft (m).

4.6. Experimental design:

The threshing machine was designed and manufactured for threshing wheat crop in Agricultural Engineering Department, Faculty of Agricultural Sciences, University of Dongola, northern state of Sudan under collaboration of Alshamaliya for Agricultural Services Company.

Wheat materials (360 kg variety Imam) was manually collected by hand pulling from the farm of the Dongola Research Station. Each half of the collected material was divided into 48 bundles (7.5 kg each) and each bundle was fed to the locally made machine.

The study operating parameters include:

Two levels of drum speed; DS1= 650 RPM and DS2= 900 RPM.

Two levels of fan speed; FS1= 1042 RPM and FS2= 1390 RPM.

Two levels of concave - drum clearance; C1= 15 MM and C2= 20 MM.

Two types of threshing drum; TD1= Rasp-bar drum and TD2= Wire-loop drum.

Randomized complete block design was used with sixty treatments replicated three times. For each replication in each treatment the following measurements was made:

Threshed grains by weight (g), Un-threshed grains by weight (g), Grains blown out with chaff by weight (g), Total grains by weight (g), Broken grains by weight (g), Grains with stem by weight (g).

Threshing efficiency (Alizadeh and Bagheri, 2009) is the ratio of total weight of grain threshed to the total weight of grains fed into the threshing, that expressed in percentage. It can be evaluated by equation (3):

Threshing efficiency (%) = $\frac{\text{Weight output}}{\text{Weight input}}$×100 %... (17)

Separation losses (Asli-Ardeh et al., 2009) is the ratio of total weight of un-threshed grain to the total weight of grains fed into the threshing that expressed in percentage. It can be evaluated by equation (4):

Separation losses (%) = $\frac{\text{Un threshed}}{\text{Weight input}}$×100 %... (18)

Cleaning efficiency (Agidi et al., 2013) is the ratio of mass of separated impurities to the total mass of impurities in the wheat expressed in percentage and is given as:

Cleaning efficiency (%) = $\frac{\text{Mass of separated impurities}}{\text{Total mass of impurities}}$×100 %........................... (19)

Product purity (Igbeka, 1984) this was obtained as the ratio of weight of whole wheat grains in the products to the total weight of products**.**

This is expressed mathematically as**:**

Product purity (%) = $\frac{\text{GP}}{\text{GP+BP}}$×100 %.....................…………..…………………....(20)

Where;

GP is the weight of clean wheat grain in the clean- grain outlet, kg.

BP is the weight of materials other than grains collected in the clean- grain outlet, kg.

The data obtained were statically analyzed using GenStat software edition 3 to determine the effect of cylinder speed, fan speed, concave-cylinder clearance and cylinder type on the above mentioned variables.

3.7. Operating principle:

The operation of the wheat crop thresher can be described as follow:

The materials from farmer-harvested wheat grain plants are fed in to the threshing cylinder to flow down freely and directly to the sieve supported by gravity and concave. while shaking, small materials other than healthy wheat grains (including broken grains and half-matured grains) drop down to the trash pan.

Air from the high capacity fan is directed to get rid of lighter trashes, whereas clean wheat grains is forwarded to the clean grain pan supported by gravity and inclination which is controlled manually by jackscrew in front of the machine (Figure 1 and Figure 2).

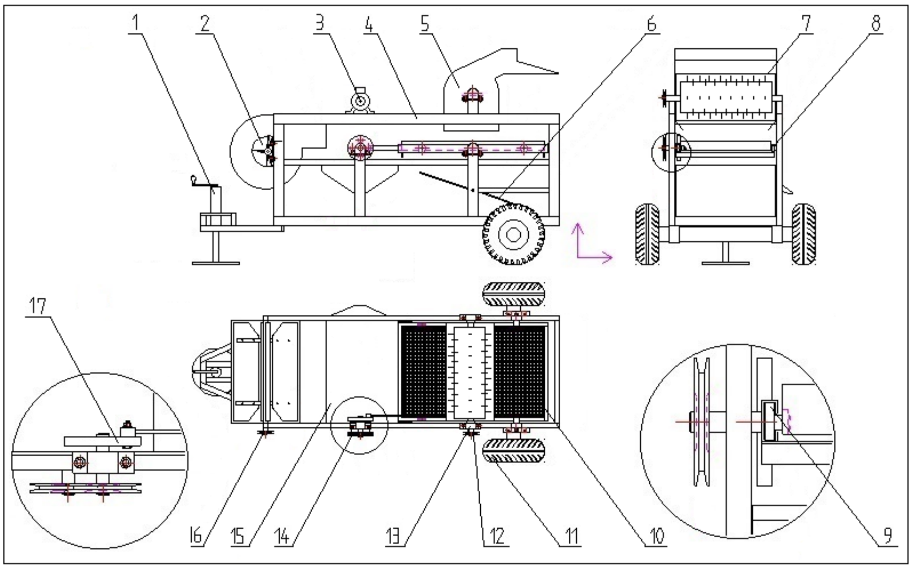

Figure 1: Schematic diagram of the wheat crop thresher

1- screw jack, 2- high capacity fan, 3- electric motor, 4- frame, 5- threshing cylinder, 6- trashes pan, 7- threshing drum, 8- shaker, 9- bearing, 10- sieve, 11- driving wheel, 12- drum pulley, 13- bearing housing, 14- shaker pulley, 15- clean grain pan, 16- fan pulley, 17- crank

4. Results and discussion:

Table 1: The study treatments and the letters assigned to each of them

Treatments	Letters
CS1×FS1×C1×TD1	A
CS1×FS1×C1×TD2	B
CS1×FS1×C2×TD1	C
CS1×FS1×C2×TD2	D
CS1×FS2×C1×TD1	E
CS1×FS2×C1×TD2	F
CS1×FS2×C2×TD1	G
CS1×FS2×C2×TD2	H
CS2×FS1×C1×TD1	I
CS2×FS1×C1×TD2	J
CS2×FS1×C2×TD1	K
CS2×FS1×C2×TD2	L
CS2×FS2×C1×TD1	M
CS2×FS2×C1×TD2	N
CS2×FS2×C2×TD1	O
CS2×FS2×C2×TD2	P

4.1 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Threshed Grains:

The influence of different drum speed, fan speed, concave-drum clearance and type of drum on threshed grains is presented in Figure 3. The results showed that the differences among treatments were highly significant ($P \leq 0.01$). The highest value recorded was (2480.7 g) under the treatment combination (O), while the lowest value was (2329.3 g) under (B). In general, the findings indicated that threshed grain output increased with increasing cylinder speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder. Similar findings were reported by Singh and Kumar (1976), Ige (1978), Sharma and Devnani (1980), Desta and Mishra (1990), Hadad (2000), Simonyan and Oni (2001), El-Haddad (2004), Vejasit and Salokhe (2004), Adewumi et al., (2007) and Radwan et al., (2009). Arnold (1964) stated that increasing concave length increased concave separation. The effect of concave length in threshing wheat and barley was also investigated by Cooper (1978), who reported that a 25% increase in arc from 84° to 105° resulted in a 17% increase in grain separation. Sarwar and Khan (1987) compared the performance of rasp-bar and wire-loop cylinders for rice threshing and reported that the rasp-bar type produced a higher percentage of husked grain than the wire-loop type at all evaluated peripheral speeds. Furthermore, Addo et al., (2004) reported that the rasp-bar drum provides a larger surface area for frictional impact, enhancing threshing performance.

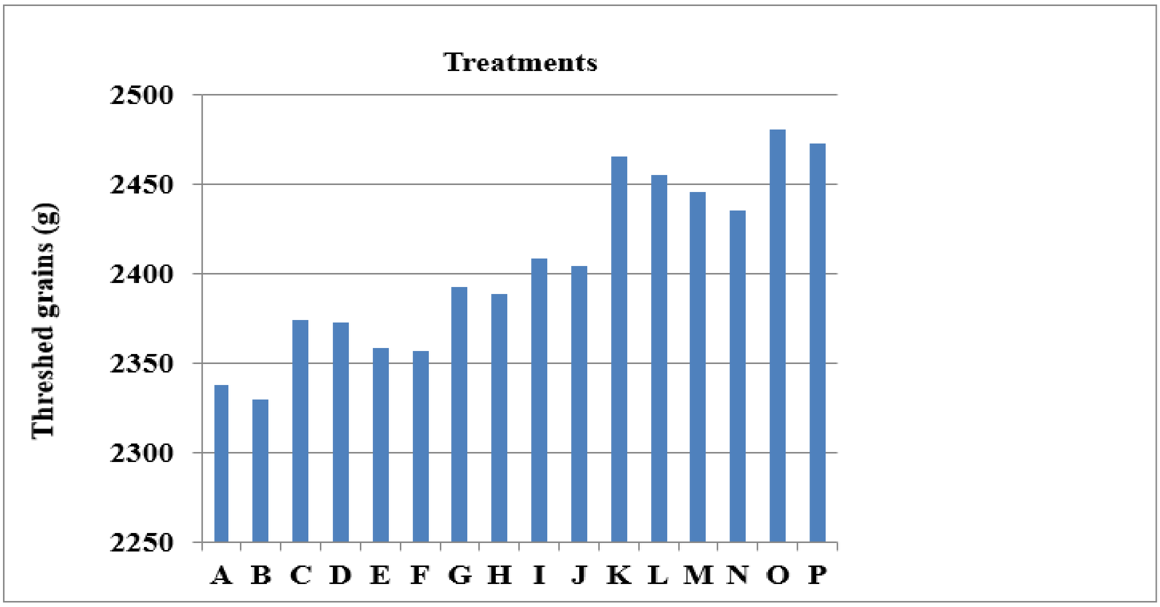

Figure 3: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Threshed Grains

4.2 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Un-Threshed Grains:

The results of un-threshed grains are presented in Figure 4. The statistical analysis revealed a highly significant difference among treatments ($P \leq 0.01$). The lowest value recorded was (698.3 g) under (O), while the highest value was (746.0 g) under (B). Overall, un-threshed grain losses decreased with increasing drum speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder. These findings are in agreement with Singh and Kumar ,(1976) who reported that increasing cylinder speed reduces un-threshed seed losses. Dash and Das (1989), during the development of a power-operated paddy thresher, stated that higher cylinder peripheral velocity is required to minimize total un-threshed losses. Abo El-Khair (1991) also concluded that un-threshed seed losses decrease as drum speed increases. Similarly, El-Haddad (2004) designed and manufactured a chopping, threshing, and winnowing machine suitable for crop residue recirculation and found that un-threshed grain losses decreased with increasing cylinder speed.

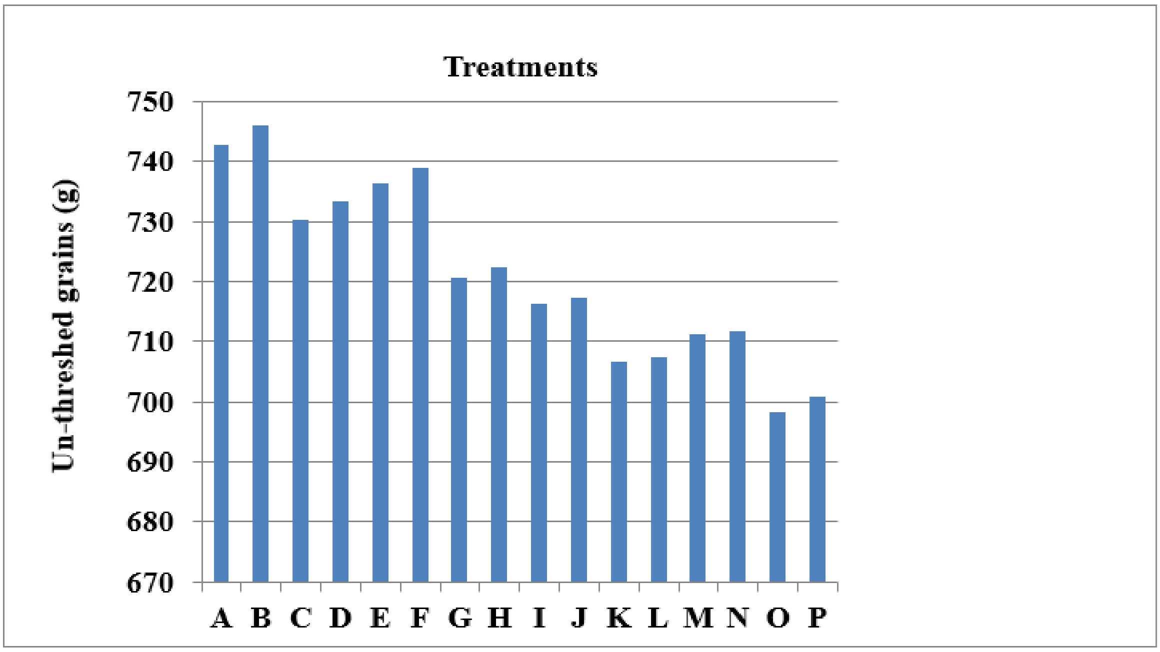

Figure 4: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Un-Threshed Grains

4.3 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Broken Grains:

The results of broken grains are presented in Figure 5 ,which showed a highly significant difference among treatments ($P \leq 0.01$). The highest level of broken grains was (125.0 g) under (O), while the lowest level was (116.0 g) under (B). In general, the results indicated that total grain damage increased with increasing cylinder speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder. Similar results were reported by Kolganov (1956), Vas and Harison (1969), Singh and Kumar (1976), Kumar and Goss (1979), Joshi and Singh (1980), Sharma and Devnani (1980), Singh et al. (1981), Anwar and Gopta (1990), Alonge and Adegbulugbe (2000), Sudajan et al. (2002), Khazaei et al., (2002), Johnson (2003), Khazaei et al., (2003), El-Haddad (2004), Vejasit and Salokhe (2004), El-Haddad et al., (2006), Askari Asli-Ardeh et al., (2008), Chimchana et al. (2008), and Ponican et al. (2009).

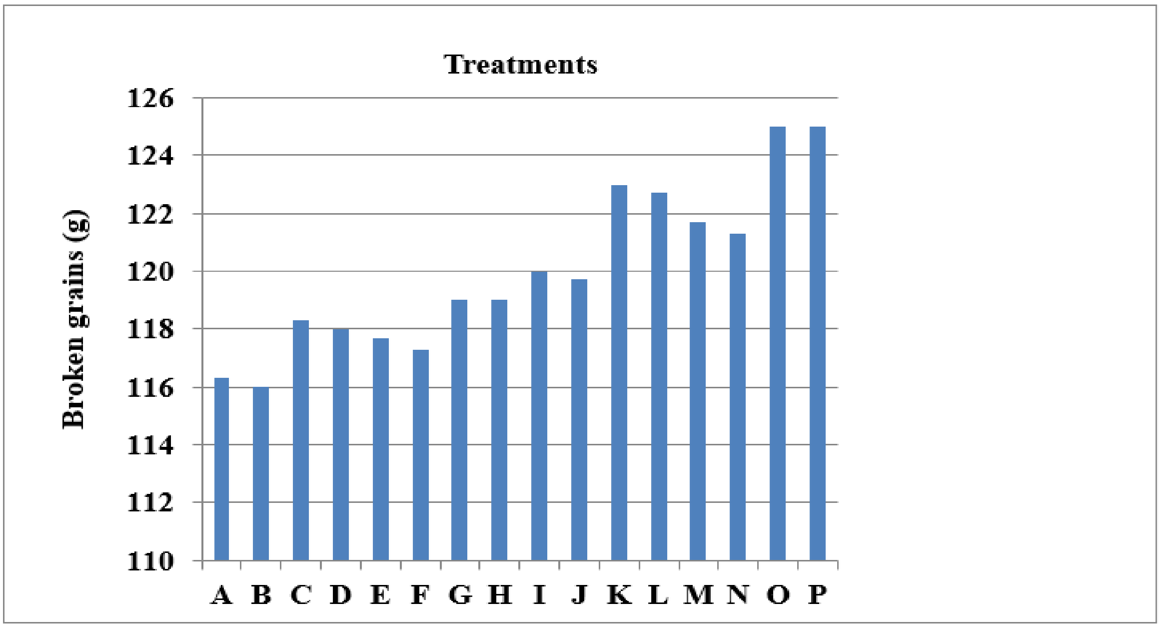

Figure 5: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Broken Grains

4.4 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Grains with Chaff:

A highly significant difference among treatments ($P \leq 0.01$) was also observed for grains with chaff, as illustrated in Figure 6. The highest value recorded was (252.7 g) under (P), while the lowest value was (232.7 g) under (B). Overall, grains with chaff increased with increasing drum speed, fan speed, and concave-drum clearance when using the wire-loop type cylinder. These findings are in agreement with Vejasit and Salokhe (2004), who studied machine-crop parameters of an axial flow thresher for soybean and reported that threshing drum speed significantly affects grain losses during soybean threshing.

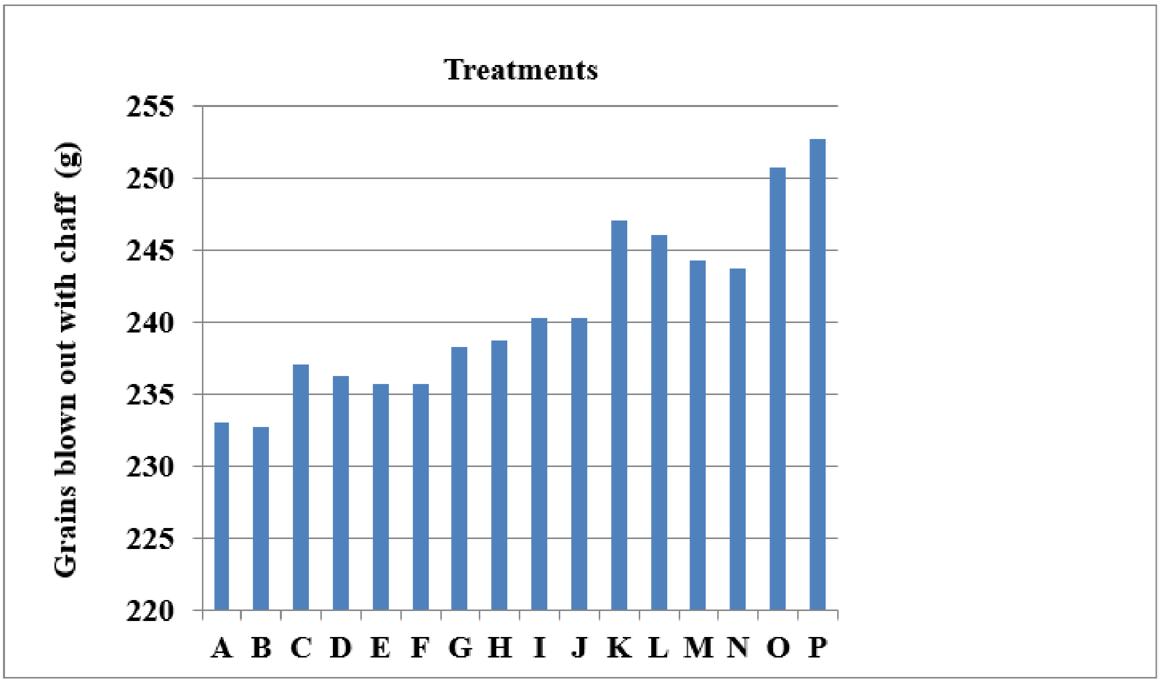

Figure 6: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Grains with Chaff

4.5 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Grains with Stem:

The results pertaining to grains with stem as influenced by different drum speed, fan speed, concave-drum clearance and type of drum are presented in Figure 7. The analysis of variance indicated a highly significant difference among treatments ($P \leq 0.01$). The highest value of grains with stem was (188.3 g) under (P), while the lowest value was (174.3g) under (A). Overall, grains with stem increased with increasing drum speed, fan speed, and concave-drum clearance when using the wire-loop type cylinder. These findings are in agreement with Vejasit and Salokhe (2004), who studied machine-crop parameters of an axial flow thresher for soybean and reported that threshing drum speed significantly affected grain losses during soybean threshing.

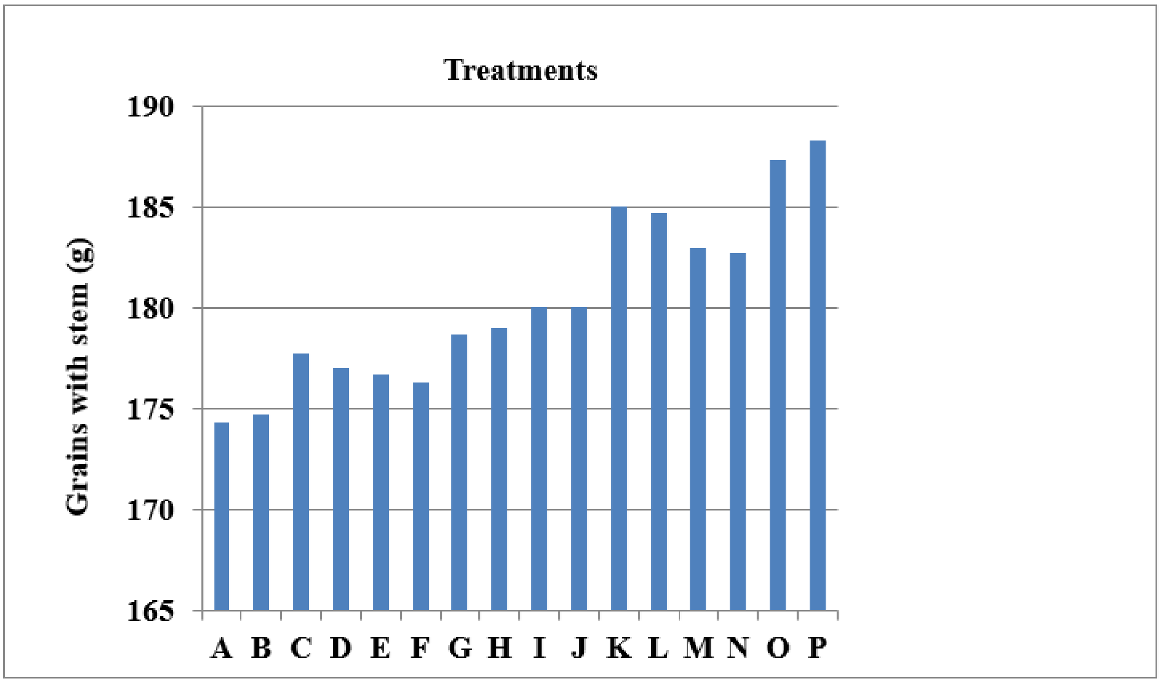

Figure 7: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Grains with Stem

4.6 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Total Grains:

The results of total grains as influenced by different drum speed, fan speed, concave–drum clearance and type of drum are presented in Figure 8. The analysis showed that the differences among treatments were highly significant ($P \leq 0.01$). The highest value of total grains was (2918.7g) under (O), while the lowest value was (2736.7 g) under (B). Overall, total grain recovery increased with increasing drum speed, fan speed, and concave–drum clearance when using the rasp-bar type cylinder.

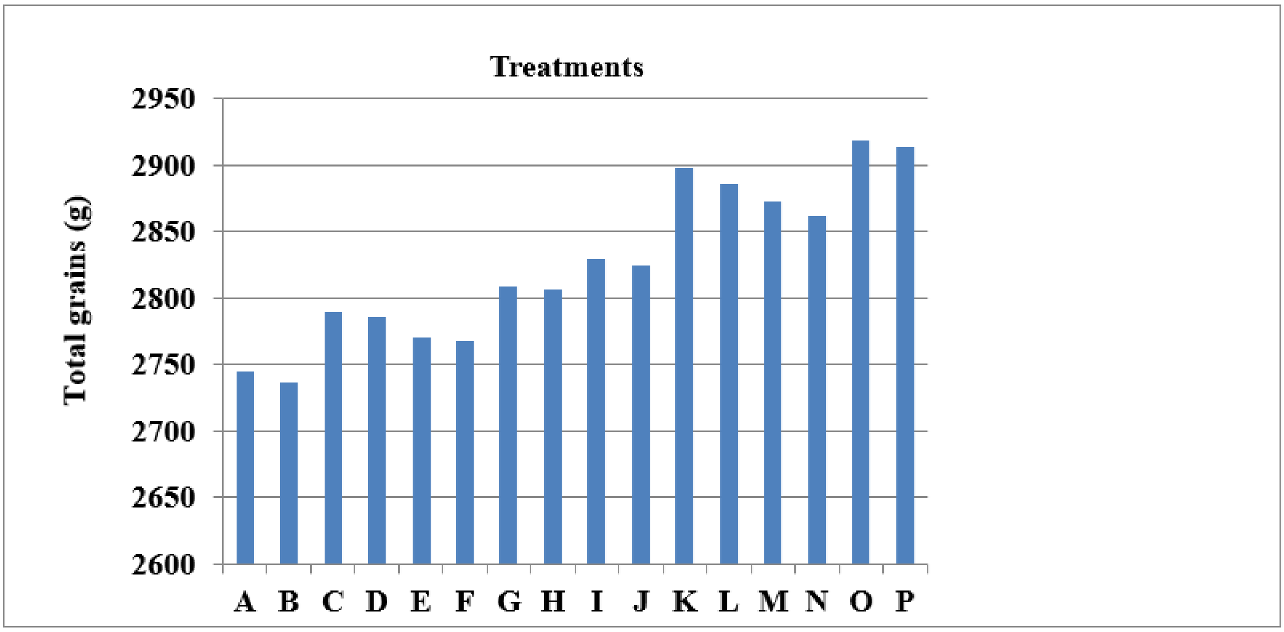

Figure 8: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Total Grains

4.7 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Threshing Efficiency %:

The effect of different drum speed, fan speed ,concave-drum clearance and type of drum on threshing efficiency is presented in Figure 9. The results showed that the differences among treatments were highly significant ($P \leq 0.01$). The highest threshing efficiency value recorded was (69.9%) under (O), while the lowest value was (65.7%) under (B). In general, the results indicated that machine efficiency is directly influenced by cylinder drum speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder. Similar findings were reported by Singh and Kumar ,(1976) Ige (1978), Sharma and Devnani (1980), Desta and Mishra (1990), Hadad ,(2000) Simonyan and Oni (2001), El-Haddad (2004), Vejasit and Salokhe (2004), Adewumi et al., (2007), and Radwan et al., (2009).

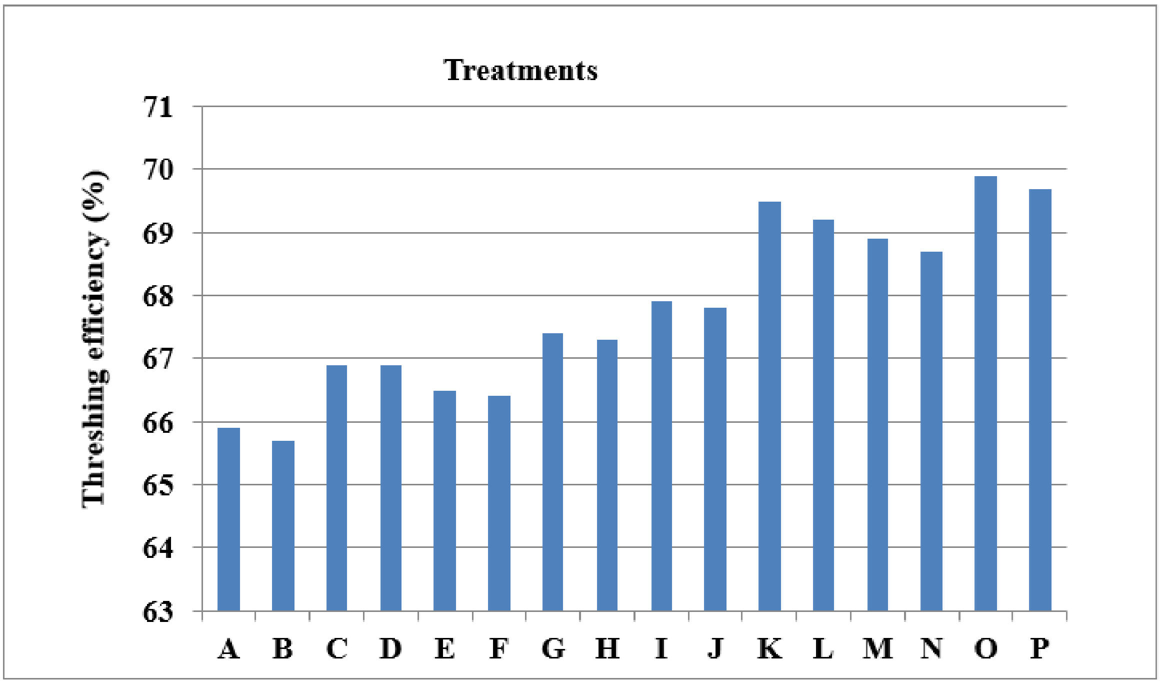

Figure 9: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Threshing Efficiency %

4.8 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Separation Losses %:

Data regarding separation losses are presented in Figure 10. The results showed that the differences among treatments were highly significant ($P \leq 0.01$). The lowest value of separation losses was (30.1%) under (O), while the highest value was (34.3%) under (B). Overall, separation losses decreased with increasing drum speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder. These findings are in agreement with Singh and Kumar (1976), who reported that increasing cylinder speed reduces un-threshed seed losses. Dash and Das (1989), during the development of a power-operated paddy thresher, stated that higher cylinder peripheral velocity is required to minimize total un-threshed losses. Abo El-Khair (1991) also concluded that un-threshed seed losses decrease with increasing drum speed. Similarly, El-Haddad (2004) designed and manufactured a chopping, threshing, and winnowing machine suitable for crop residue recirculation and found that un-threshed grain losses decreased with increasing cylinder speed. Arnold (1964) reported that increasing concave length increases concave separation. Cooper (1978) further showed that a 25% increase in concave arc from 84° to 105° resulted in a 17% increase in grain separation.

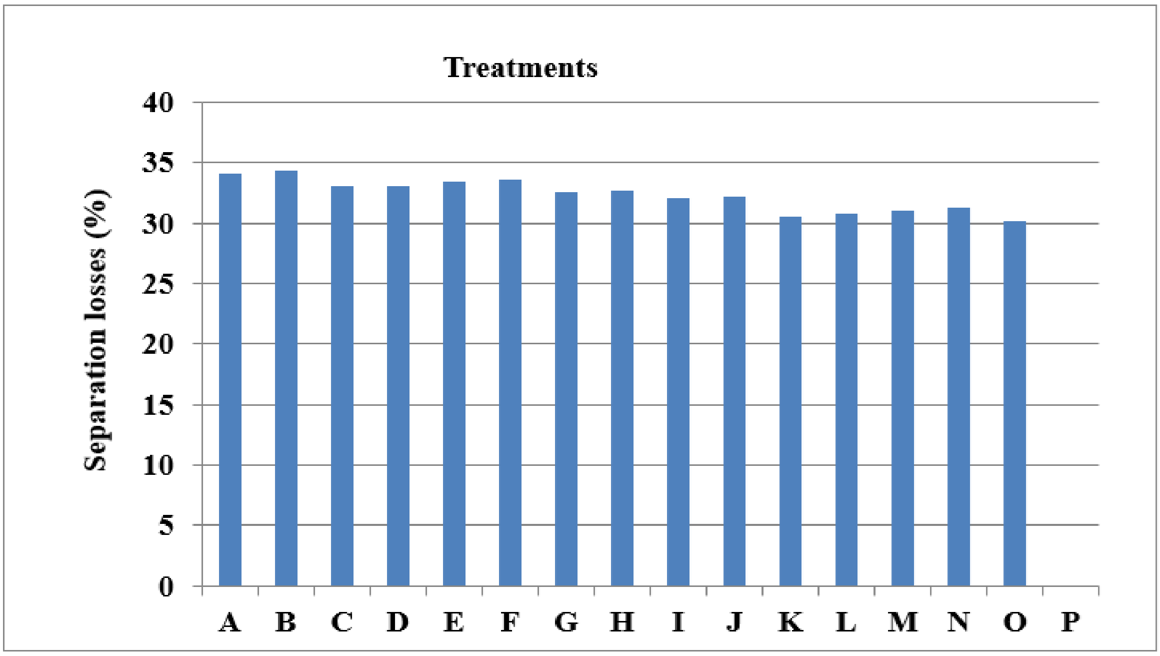

Figure 10: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Separation Losses %

4.9 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Cleaning Efficiency %:

The results pertaining to cleaning efficiency as influenced by different drum speed, fan speed, concave-drum clearance and type of drum are presented in Figure 11. The analysis of variance indicated a highly significant difference among treatments ($P \leq 0.01$). The highest cleaning efficiency was (82.3%) under (O), while the lowest value was (77.2%) under (B). Overall, cleaning efficiency increased with increasing drum speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder. These results are in agreement with Joshi and Singh (1980), who developed the Pantnagar IRRI multi-crop thresher and observed that cleaning efficiency increased with an increase in cylinder speed.

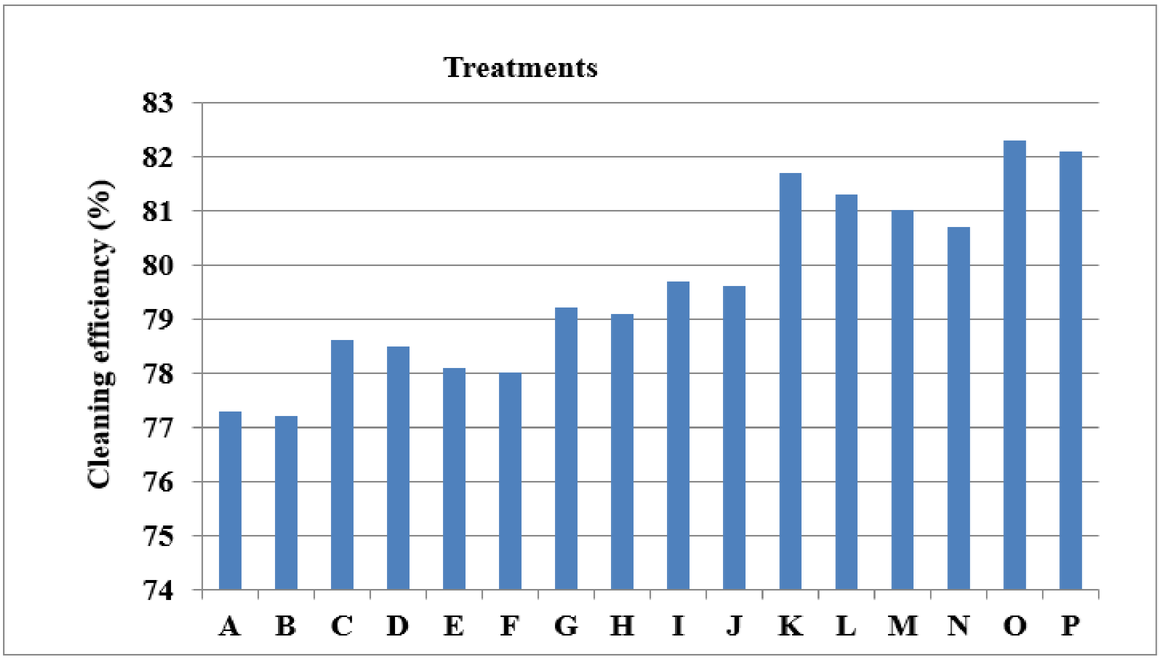

Figure 11: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Cleaning Efficiency %

4.10 Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Product Purity %:

The effect of different drum speed, fan speed, concave-drum clearance and type of drum on product purity is presented in Figure 12. The results showed that the differences among treatments were highly significant ($P \leq 0.01$). The highest value of product purity recorded was (89%) under (O), while the lowest value was (93.2%) under (B). Overall, product purity increased with increasing drum speed, fan speed, and concave-drum clearance when using the rasp-bar type cylinder.

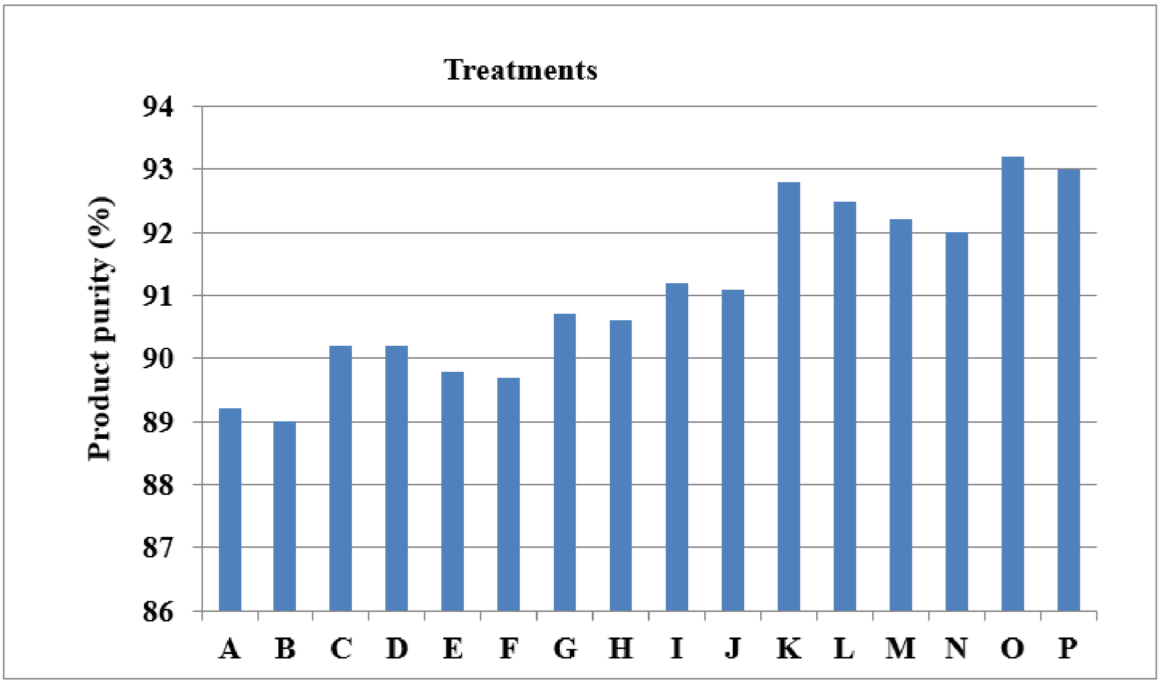

Figure 12: Effect of different drum speed, fan speed, concave - drum clearance and type of drum on Product Purity %

5. Conclusions:

Increasing cylinder speed, fan speed, and concave-drum clearance improved threshing efficiency, cleaning efficiency, and product purity up to an optimum level, particularly with the rasp-bar cylinder which performed better than the wire-loop cylinder; however, further increases in these parameters also led to higher grain damage and increased grain losses in the form of grains mixed with chaff and stems, indicating a trade-off between improved separation performance and increased mechanical damage and losses, with the best overall performance achieved under the (O) treatment. The threshing efficiency, separation losses, cleaning efficiency and product purity which were 69.9 %, 30.1 %, 82.3 % and 93.2 % respectively.

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