Study of Different Kinds of Threshers & Factors Influencing threshing of Crops: A Review

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Abstract— The review of previous research works related to mechanism of threshing employed for various crops, influence of crop, machine and operational parameters on the design of threshers are presented under the following subtitles. Mechanical threshing of crops, Factors affecting efficiency of threshing operation, Speed of threshing cylinder, Concave clearance, Type of threshing cylinder, Moisture content of crop, and Performance evaluation of threshers.
Key words: Different Kinds of Threshers, Farm Machinery

I. INTRODUCTION

The traditional method of threshing often results in some losses due to the grain being broken or buried in the earth. This process is slow and energy consuming. Often this local method of processing the crop leads to low quality product, due to the presence of impurities like stones, dust and chaff. Threshing and separation of the grain from these impurities requires modern technology that can be easily maintained and repaired for effectively utilization.

II. MECHANICAL THRESHING OF CROPS

Threshing is a major post-harvest operation which is carried out after all crops have been gathered from the field. Mechanical threshing involves high technology which is very expensive, though it helps to maintain the quality of the final products; it eliminates drudgery associated with local threshing system and reduces threshing losses (Olaoye, 2011).

Moisture content of the ear-head plays a key role in threshing operation and seed quality. The traditional methods of threshing are tedious, time consuming and inefficient in operation. Some of the important parameters which influence the threshing efficiency are mechanical damage, moisture content, threshing cylinder speed, feeding rate and concave clearance (Naveenkumar *et al*. 2013).

In order to help small scale agriculture, increase its contribution in ensuring food security in the country, all aspects of production including harvest, threshing and post-harvest handling of the produce, need equal and proper attention. Threshing is one of these activities which are a slow and tedious process. Threshing or shelling is the process of separating the grain from the seed heads, panicles, cobs or pods of the crops. It is important to minimize the damage done to grain during threshing as damaged grain is much more prone to attack by insects and fungi. Consequently, techniques that crush and damage grains such as beating with sticks or trampling by cattle are not recommended. Traditional threshing of crops like wheat, barley and sorghum is one of the time consuming, laborious and in which grain loss occurs (Abagisa *et al.* 2015).

Threshing is the separation of seeds or grains from the pods or heads of crops. The earliest method of threshing was to beat the grains out with sticks. This arduous task was first simplified whereby the grain heads are spread out on a hard surface or ground and oxen are driven over them to trample out the grains from the heads. Threshing is done traditionally by placing the harvested produce on the floor of mud or concrete and beaten with a stick or flailed. Other methods include the use of mortar and pestle to remove the seeds. These methods of threshing, however, are not convenient enough since the output is very low, sometimes contaminated, time consuming and requires high labor. The mechanical method of threshing has the advantage of being labor free and time saving; in addition, it increases the quality of production. (Omale *et al*. 2015).

Traditionally threshing of millet crop is done either beating by sticks or by treading out the crop panicle under the feet of oxen. These threshing operations are most time consuming, energy intensive (19.9 $kJmin^{-1}$), labour intensive, drudgery prone and uneconomical. The mechanized threshing of millets can reduce the drudgery of farmers/labours, improve the quality of product (Singh *et al*. 2015).

Mechanical motorized corn sheller and thresher gives more desirable results than manual conventional method of corn shelling and threshing. It tends to saving of the time and also leads to save money. It is desirable to use low cost corn sheller and thresher for economical work and to increase the productivity (Kedar Patil *et al*. 2016).

Careless threshing can reduce the quality of the products and bring subsequent losses from the action of insects and post-harvest diseases. Manual system of soybean threshing is characterized with time wastage, threshing losses, and high drudgery. The mechanical threshing which involves high technology helps to maintain the quality of the final products eliminates drudgery associated with local threshing system and reduces threshing losses (Timothy Adesoye Adekanye 2016).

III. FACTORS AFFECTING EFFICIENCY OF THRESHING OPERATION

The factors affecting the thresher performance were classified into three groups.

1) Crop factors
   - Variety of crop
   - Moisture content of crop
2) Machine factors
   - Feeding chute angle
   - Cylinder type and diameter
   - Spike shape, size and number
   - Concave size, shape and clearance

3) Operational factors
   - Cylinder speed
   - Feed rate
   - method of feeding
   - Machine adjustment

Researchers have to pay great attention to these factors and try to obtain optimal parameter values by varying these parameters at different levels (Osueke, 2011).

Kepner *et al.* (1978) discussed the factors affecting the efficiency of threshing operation. They identified the factors as feeding method, cylinder speed, concave to cylinder clearance and moisture content.

Huynh *et al.* (1982) stated that the seed separation from the stalks and passage of seed through the concave grate is a function of some variables such as crop feed rate, threshing speed, concave length and cylinder diameter and concave clearance. These variables are also related to the threshing losses and seed separation efficiency.

Kaul and Egbo (1985) stated that the performance of a thresher depends upon its size, cylinder speed, cylinder concave clearance, fan speed and the sieve shaker speed.

Tandon *et al*. (1988) considered five parameters that influenced threshing efficiency and kernel damage, namely, cylinder peripheral speed, cylinder type, concave type, concave clearance and grain moisture content. They reported that concave clearance and cylinder peripheral speed had significant effect on the threshing efficiency and grain damage for pulse threshers.

Dauda (2001) reported that the high moisture content and low cylinder speed tend to reduce the percentage of damage seed, blown seed and seed loss respectively while low moisture content and high speed tends to increase the percentage of damage seed, blown seed and seed loss respectively. Moisture content state and impact on grain during threshing are paramount in determining crop mechanical damage.

Wacker (2003) investigated the effect of several wheat varieties on performance of threshing. The results showed that moisture content, cylinder speed and space between concave and cylinder were effective on wheat threshing.

Ajayi *et al*. (2014) investigated the comparative quality and performance analysis of manual and motorized traditional portable rice threshers and stated that the threshing effectiveness results from the combination of the factors viz., the peripheral speed of the threshing cylinder, cylinder concave clearance, and number of rows of concave teeth used with a spike tooth cylinder and the varieties of rice. The optimized value of 500 rpm of threshing cylinder speed resulted in time saving, reduction in percentage seed loss and percentage mechanical damage. The cost of operation is also reduced and the quality of produced rice is enhanced.

A. Speed of Threshing Cylinder

Vas and Harrison (1969) investigated the effect of mechanical threshing parameters on kernel damage and threshability of small grains. It is concluded that the cylinder speed is the primary influencing parameter while concave clearance, although of less significance, is an important factor as well.

Gol and Nada (1991) evaluated the performance of power operated groundnut pod stripper and reported that the important factors affecting the efficiency of the mechanical pod stripping element are speed of operation and condition of crop. The percentage of shelled pods increased by 0.1 to 3 per cent with increase of the cylinder peripheral speed from 473 to 675 m min^{-1}.

Ajav and Adejumo (2005) developed a okra thresher and evaluated with three different levels of cylinder concave clearance (10, 20, 30 mm), three levels of seed moisture content (12.5, 14.0. 17.0 per cent), two levels of cylinder speed (4.2 and 4.4 ms^{-1}), and feed rate of 10 kgh^{-1} of dried okra pods and the performance was found to be a maximum of 97 per cent threshing efficiency and 97.7 per cent cleaning efficiency, a minimum of 3.3 per cent total seed loss and a maximum germination of 85 per cent at 30 mm concave clearance, 4.2 ms^{-1} cylinder speed and 17 per cent moisture content.

Somposh Sudajan *et al.* (2005) investigated the power requirement and performance factors of a sunflower thresher at five levels of drum speeds (650, 700, 750, 800 and 850 rpm) and three feed rates (2000, 2500 and 3000 kg(head)h^{-1}). They concluded that the optimum combination of drum speed and feed rate of a rasp-bar sunflower thresher in order to obtain the higher output capacity, threshing efficiency, lower grain damage, grain losses, specific energy consumption at 2000 to 3000 kg(head)h^{-1} feed rate was a combination of 700 to 800 rpm (10.99 to 11.73 ms^{-1}) drum speed, 35 mm concave clearance and 11x 60 mm concave hole size. The developed sunflower thresher if operated at these combinations of parameters yielded the optimum performance.

Emara (2006) conducted an investigation to modify the threshing drum of a local stationary thresher to suit the separation of flax seeds with minimizing the stalk damage. An automatic device for determining the separating times and giving signal after separating the seeds has been designed and fabricated. The thresher was evaluated under four feed rates of 8.57,12.86, 17.14 and 21.43 kg min^{-1} and four drum speeds of 24.25, 25.81, 27.33 and 28.85 ms^{-1}, two threshing drums of 8 and 12 fingers arranged in five sets each and three separating times of 10, 15 and 20 seconds. The machine productivity (seed output), seed loss, stalks damage and energy requirements have been determined. The developed thresher productivity, seed and stalk damage, threshing efficiency and energy required for separating flax seeds had been positively affected by feed rate, drum speed, number of drum fingers and separating time. On the other hand, the unthreshed seed were positively and negatively affected by the feed rate and drum speed respectively, for the other different treatments. The drum fingers of 12 and separating time of 15 seconds of the developed stationary threshing machine gave the maximum productivity and threshing efficiency and minimum values of seed, stalk damages, energy consumed and criterion costs compared with the drum fingers of 8 and separating times of 10 and 20 seconds. The results showed that development of the threshing drum led to improve the performance of the stationary thresher, especially productivity and efficiency in addition to decreasing the seed losses and stalk damage compared with the machine before development. The optimum performance for the developed thresher for separating flax seeds was at drum speed of 28.85 ms^{-1}, feed rate of 8.57 kg min^{-1}, and drum fingers of 12 and separating time of 15 seconds. The maximum threshing efficiency of these conditions was 96.92 per cent but the minimum unthreshed seed losses, seed and stalk damage and energy were 1.33, 3.48, 3.26 per cent and 1.262 kW, respectively.

Sessiz *et al.* (2007) evaluated soybean threshing efficiency and power consumption for different concave materials with four concave types were PVC, rubber, chromium, and steel plate with three feed rates (360, 720 and 1,080 kg h^{-1}) and five beater peripheral speeds (7.95, 9.10 10.54, 12.16 and 14.66 ms^{-1}). They concluded that the threshing efficiency decreased with increasing feed rate and increased drum peripheral velocity significantly improved the threshing efficiency. The highest threshing efficiency was achieved with the chromium type of beater, followed by PVC, the sheet iron, and the rubber.

Ray Langham *et al.* (2008) stated that as sesame enters the cylinder or rotor, the abrupt change in direction does the majority of the threshing. The immediate direction change force cracks the capsule, releasing the seed. The open concave prevents the sesame from being scuffed or broken. The slow speed of threshing cylinder allows the seed to be gently dumped from the capsule. They recommended that the threshing cylinder for sesame threshing have to be gentle on the crop (350-500 rpm).

Simonyan and Oni (2009) developed and investigated a sorghum thresher with the performance variables investigated viz., threshing efficiency, cleaning efficiency and cleaning loss at six threshing speeds (2.64, 3.64, 4.4, 5.03, 5.78 and 6.28 ms^{-1}), six air speeds (3.67, 4.67, 5.17,5.47, 7.33 and 8.33 ms^{-1}), five sieve oscillation speed (0.59, 0.88, 1.47, 2.05 and 2.64 ms^{-1}) and five feed rates (492.86, 521.43, 640, 720 and 740 kgh^{-1}). The highest threshing efficiency of 99.96 per cent was obtained at a cylinder threshing speed of 5.78 ms^{-1}, and feed rate of 640 kgh^{-1}.The highest cleaning efficiency of 96.14 per cent was obtained at a threshing speed of 3.64 per cent, air speed of 4.67 ms^{-1}, sieve oscillation speed of 0.88 ms^{-1}.

Alizadeh and Khodabakhshipour (2010) investigated the effect of threshing drum speed and crop moisture content on the paddy grain damage in axial-flow thresher at five levels of 450, 550, 650, 750 and 850 rpm, and at three levels of paddy moisture content of 17.0, 20.0 and 23.0 per cent (w.b.) on the broken and cracked grains. The results revealed that the most broken grains of 0.68 per cent was recorded at drum speed of 850 rpm and paddy moisture content of 17 per cent and the least value was obtained at drum speed of 450 and 550 rpm and paddy moisture content of 23.0 per cent. The cracked grains increased from 7.0 to 37.0 per cent, 6.67 to 25.0 per cent and 14.0 to 17.30 per cent at paddy moisture contents of 17.0, 20.0 and 23.0 per cent, respectively as the drum speed increased from 450 to 850 rpm. The most grain damage was measured at moisture content of 17.0 per cent (w.b.) and the least was obtained at moisture content of 23.0 per cent (w.b.).

Baldev Dogra *et al.* (2013) evaluated the performance of a modified commercially available with spike tooth type wheat thresher for threshing lentil (Lens Culinaris) at four levels of peripheral speed of threshing cylinder (18.2, 20.1, 21.9 and 23.7 ms^{-1}) and three levels of feed rate (7.5, 9.0, 10.5 qh^{-1}) and concluded that the peripheral speed and feed rate play an important role in affecting threshing efficiency, cleaning efficiency and breakage of lentil crop. The per cent grain breakage was higher for higher peripheral speed and lower for higher feed rate. For threshing of lentil with a modified commercially available wheat thresher the peripheral speed of 21.9 ms^{-1} and feed rate of 10.5 qh^{-1} was optimum. At this combination, the grain damage, non-collectable losses, cleaning efficiency and threshing efficiency were 0.98, 0.60, 98.28 and 99.45 per cent respectively.

Olaye *et al.* (2016) investigated an axial-flow spike-tooth thresher with cylinder speed of four levels (600, 800, 1000 and 1200 rpm) and three samples of paddy weighs (40, 50 and 60 kg) and three replications on capacity per hour. It is revealed that the mean threshing capacity ranged from 1326 to 2013 kgh^{-1}, mean fuel consumption ranged between 0.75 to 0.84 $mLkg^{-1}$, threshing efficiency was 100 per cent. The mechanical seed damage ranged from 2.63 to 16.45 per cent. The cleaning efficiency ranged 95.57 to 96.79 per cent, while the seed loss from 0.88 to 4.23 per cent for the four speeds.

B. Concave Clearance

Sharma and Devnani (1979) determined the effect of cylinder tip speed and concave clearance of a rasp bar thresher on threshing of sunflower. Threshing trials were carried out by varying the cylinder tip speed from 4.81 to 8.17 ms^{-1} and concave clearance from 4 to 12 mm. All threshing parameters were highly correlated with the cylinder tip speed and concave clearance. The germination percentage was directly proportional to the concave clearance and inversely proportional to the cylinder tip speed.

Desta and Mishra (1990) conducted performance evaluation of a sorghum thresher, with three levels of feed rate (6, 8,10 $kgmin^{-1}$), two levels of cylinder concave clearance (7 and 11 mm) and three levels of cylinder speed (300, 400 and 500 rpm). They showed that threshing efficiency increased with an increase in cylinder speed for all feed rate and cylinder concave clearances. The threshing efficiency was found in the range of 98.3 to 99.9 per cent.

Yilmaz *et al*. (2008) investigated the effect of some of the threshing parameters such as drum speed, feed rate and concave open on closed capsules sesame straw sieve in developed threshing unit. Threshing drums used were a rasp bar with tooth type, three threshing drum speeds of 500, 700 and 900 min^{-1} (6.5, 9.1, 11.7 ms^{-1}), three feed rate as (90, 180 & 270 kg h^{-1}), three concave open as (20, 35 and 50 mm), four sieves of mesh numbers (7, 10, 14 and 18) were used. They concluded that the 10, 14 and 18 mesh number sieves should be used for separation of sesame stalk and grain. The design of separation unit should depend on these sieves. The best performance of the sieves gave at 900 min^{-1} drum speed, 90 kgh^{-1} feed rate and 20 mm concave open for separation of the sesame stalk and grain.

Saeidirad *et al.* (2013) investigated the effect of cylinder speed with four levels (13, 17, 21 and 25 ms^{-1}), concave clearance (5, 10 and 15 mm) and feed rate (420, 500 and 590 kgh^{-1}) on un-separated seed percentage, damaged seed percentage and germination of sorghum. They concluded that the threshing cylinder speed had a significant effect on unseparated seed percentage and damaged seed percentage. The concave clearance created a significant effect on damaged seed percentage. Though the feed rate did not have significant effect on all adjectives, the unseparated seed percentage increased with increasing of feed rate. The thresher efficiency and damaged seed increased with increase of cylinder speed. The increase of concave clearance from 5 to 10 mm caused that unseparated seed weight percentage increased from 0.69 to 0.78 per cent, and damaged seed rate decreased from 13.01 to 11.01 per cent. Generally, the best performance for sorghum threshing was given at the 21 ms^{-1} cylinder speed, 10 mm concave clearance and 590 kgh^{-1} feed rate.

Adekanye and Olaoye (2013) evaluated a motorized thresher and a treadle cowpea thresher in terms of threshing efficiency (per cent), throughput capacity (kgh^{-1}), cleaning efficiency (per cent), mechanical damage (per cent) and percentage loss (per cent) for three commonly grown cowpea with three varieties (994, IAR48 and TVX), three-cylinder concave clearances (13, 12 and 11 mm), three levels of moisture contents (12.5, 15 and 17 per cent wet basis). They concluded that for motorized thresher, threshing efficiency varied from 71.4 to 82.86 per cent, 73.56 to 87.14 per cent and 77. 63 to 88.57 per cent while for treadle thresher threshing efficiency varied from 20.50 to 24.29 per cent, 21.50 to 25.71 per cent and 25.05 to 28.57 for 994, IAR48 and TVX varieties respectively. The highest cleaning efficiency of 80.77 per cent was obtained at 610 rpm for 994 cowpea variety for motorized thresher. Least damage of 6.00 per cent and 7.5 per cent were observed at 405 and 406 rpm for IAR48 and 994 varieties for motorized and treadle threshers respectively. A throughput capacity of 66.06 $kgh^{-1}$was obtained at moisture content of 12.5 per cent wet basis and 405 rpm throughput capacity of treadle thresher was 55.51 kgh^{-1} at moisture content of 17 per cent wet basis and 610 rpm.

C. Type of Threshing Cylinder

Sarwar and Khan (1980) compared the performance of rasp-bar and wire-loop cylinders for threshing rice crop. They reported that the rasp-bar gave higher percentage of husked grain than wire-loop for all levels of evaluated peripheral speeds.

Anwar *et al*. (1991) tested extensively the axial flow thresher on chickpea (CM - 72). It is observed that cylinder speed, feed rate and cylinder concave clearance affected the thresher performance in terms of grain damage, total machine loss, threshing and cleaning efficiencies. It was observed that the thresher had maximum crop intake capacity of 380 kgh^{-1} due to difficult feeding, hence resulting in low grain output. Therefore, the study suggested that raspbar threshing system with easy feeding method should be tested for chickpea threshing.

Vejasit (1991) compared the performance of the rasp bar and peg-tooth threshing drums of an axial flow thresher for soybean crop. The results indicated that amount of grain retained on threshing unit for both cylinder at all cylinder speeds and feed rates were not significantly different.

Rizvi *et al.* (1993) compared the performance of different threshing drums for sunflower threshing. The study showed that the peg type cylinder with a speed range of 400 to 500 rpm and a concave clearance range from 2.54 to 3.00 cm can be used for a sunflower threshing unit.

Pickard (1955) investigated the effect of cylinder and concave bar variations on the threshing of corn. He reported that the rasp-type cylinder bar appeared to be superior to the angle cylinder bar in terms of shelling efficiency and kernel damage. Covering the cylinder or concave bars with rubber had little effect on shelling efficiency or kernel damage.

Chandrakanthappa *et al*. (2001) evaluated the wireloop and raspbar threshing methods for primary processing of finger millet and stated that the rasp bar type thresher was the best among two methods of threshing.

Sudhajan *et al.* (2002) investigated the effect of type of drum (peg tooth with an opening threshing drum, peg tooth with a closed threshing drum, and a rasp bar drum), drum speed (550, 750, 950, 1150 rpm) and feed rate (1000, 2000, 3000, 4000 kgh^{-1}) of sunflower threshing on output capacity, threshing efficiency, grain damage, grain losses, material other than grains (MOG) separation. They concluded that the threshing efficiency was found to be in the range of 99.8-100 per cent for all the threshing drums, drum speeds and feed rates. The percentage of material other than grain (MOG) separated through the concave by the rasp bar drum was lower than for the other two types. This means that the rasp bar drum gave the best sunflower threshing performance. The output capacity, threshing efficiency, grain damage, grain losses and specific energy consumption at 750 rpm drum speed and 300 kgh^{-1} feed rates were 1038 kgh^{-1}, 99.99 per cent, 1.39 per cent and 3.01 $kWht^{-1}$ respectively.

Shiv Kumar Lohan (2008) investigated the effect of threshing cylinders on seed damage and viability of moong bean with hammer mill, spike tooth and raspbar threshing cylinders and reported that threshing performance and damage of seeds is affected by several parameters, viz., type of threshing cylinder, moisture content of crop, cylinder speed, feed rate and concave clearance.

Saeidirad and Javadi (2011) investigated the effect of cumin thresher with three levels of cylinder speed (12.8, 16.5 and 22 ms^{-1}), two levels of feed rate (500 and 750 kg $(plant)h^{-1}m^{-1}$), two levels of concave clearance (5 and 10 mm), two levels of cylinder type (rubber and rasp bar) and two levels of moisture content (7 and 13 percent - w.b.). The rotational speeds of 350 mm diameter thresher cylinder were 700, 900 and 1200 rpm corresponding to 12.8, 16.5 and 22 ms^{-1} peripheral velocity respectively. The results showed that with the increase of cylinder speed from 12.8 to 16.5 ms^{-1}, the percentage of separated seed, shattered stems and damaged seed increased. The cylinder type did not have significant effect on weight percentage of separated seed, while it had a significant effect on shattered stems and damaged seeds. They reported that as moisture content increased from 7 to 13 per cent, separated seed and damaged seed decreased from 92.8 to 90.4 per cent and from 10.1 to 7.6 per cent respectively.

Prasannakumar and Naveenkumar (2012) evaluated the rasp bar thresher for finger millet with the varieties of ragi MR1 and HR911, two levels of speed (960 & 1200 rpm), three levels of moisture contents (18.20,15.20, and 9.8 per cent w.b.). The rasp bar thresher has given the maximum grains output of 140.5 kgh^{-1} for variety MR1 and 130.3 kgh^{-}

^{1} for variety for HR911. They conclude that the raspbar type thresher showed the least cost for MR1 Rs.18.4 and HR911 Rs.19.5 per quintal for threshing operation and threshing of ragi crop at 10 to 13 per cent grain moisture content is recommended for adoption.

Dhananchezhiyan *et al*. (2013) developed two types of threshing cylinders, namely cast iron rasp bar threshing cylinder and nylon rasp bar threshing cylinder and fitted with portable paddy thresher. Each threshing cylinder was tested for its performance in terms of threshing efficiency and grain damage at different levels of factors viz., concave clearance (15, 20, 25 mm), cylinder peripheral speed (11.7, 14.1, 16.5 ms^{-1}), grain moisture (13.5, 16.5 and 19.5 per cent) and feed rate (200, 400, 600 kgh^{-1}). Comparing the maximum threshing efficiency, minimum grain damage in different combinations was achieved at 20 mm concave clearance, 16.5 ms^{-1}cylinder speed, 13.5 per cent moisture content and at a feed rate of 600 kgh^{-1}. The grain damage occurred at this combination was 2.76 and 1.73 per cent respectively, for cast iron rasp bar and nylon rasp bar threshing cylinders. The threshing efficiency occurred at this combination was 99.95 and 99.93 per cent respectively, for cast iron rasp bar and nylon rasp bar threshing cylinders.

ErkutPeksen *et al.* (2013) designed and manufactured a stationary chickpea threshing unit and evaluated with three different beater types (spike-tooth, lama-tooth and wire loop, two different types of concave (manufactured from PVC and chrome), five peripheral speeds (19.0, 14.5, 12.5, 10.5 and 8.0 ms^{-1}), five concave clearances (15, 20, 25, 30 and 35 mm) and four feeding rates (360, 540, 720 and 900 kgh^{-1}) and concluded that the wire loop was the best one among all beaters for threshing due to minimal seed breakage, lowest invisible injury of the seeds accompanied with high field emergence and highest threshing efficiency. Any of PVC and chrome concave can be recommended for use in the threshing unit as these were not different from each other in their performance.

Kaankuka *et al.* (2014) designed a thresher for acha and evaluated with three different rasp bar cylinder types (open, closed and abrasive) using three levels of cylinder speeds (1630, 2200 and 2800 rpm) and cylinder-concave clearance of 10 mm was kept constant and they concluded that the abrasive cylinder type gave a better performance at threshing cylinder speed of 2800 rpm.

D. Moisture Content of Crop

Inglett (1970), stated that threshing is difficult at a moisture level content above twenty-five percent (25 per cent). At this moisture content, grain-stripping efficiency is very poor with high operational energy and high level of mechanical damage to grains. A more efficient threshing is achieved when the grain is dried (13-14 per cent) moisture content.

Harrison (1975) investigated the effect of moisture content of wheat on threshing the cultivar park at five levels of variables of moisture content from 12 to 20 w.b., three levels of cylinder speed (700,900, and 1100 rpm) with a cylinder diameter of (533 mm) and three levels of feed rate (45, 68 and 91 kg min^{-1}). The concave clearance was fixed. They arrived that the least damage occurring at 20 per cent moisture content for all the cylinder speeds, but a minimum occur at 14 per cent moisture content for the 1,100 rpm level and the cylinder speed and feed rate interaction, the damage was minimum for 45 kg min^{-1}, maximum for 68 kg min^{-1} at the 700 rpm level.

Oni and Ali (1986) investigated the factors influencing the threshability of maize and reported that the factors influencing threshability of maize are field drying, maize varieties, ear size, and cylinder speed and feed rate. The properties of the crop that affect the thresher performance are crop variety, shape and size, hardness of the seed, the moisture content of the seed and the density.

Alonge and Adegbulugbe (2000) stated that kernel damage increases as the speed of the machine increases, kernel breakage increased with increases in moisture content of the kernels and that varieties of grains (maize) grown were also observed to exert some influence on the level of losses and the degree of husking.

Kamble *et al*. (2003) evaluated a pearl millet thresher and reported that threshing efficiency was reduced with increase of moisture content because high moisture content increased the plasticity of grain.

Khazaei (2003) reported cylinder speed and moisture content had significant effect on chickpea threshing efficiency and damaged grain percentage, but pea variety did not have significant effect on threshing efficiency and damaged grain percentage.

Naravani and Panwar (1994) investigated the effect of the impact mode of threshing on the threshability of a sunflower crop. The results showed that threshing efficiency increased as the impact energy increased at seed moisture contents ranging from 5.76 to 13.56 percent (w.b.). The threshing efficiency of 71 percent with 9.7 percent (w.b.) seed moisture content at an energy level of 20.6 Nm was observed.

Joshi *et al.* (1994) developed a sunflower thresher and tested with two levels of threshing drum speeds (500 and 700 rpm), three levels of feed rates (300, 240 and 180 kgh^{-1}), at seed moisture of 9.2 per cent and 12.8 per cent. Each combination of drum speed and feed rates were replicated thrice and they observed that the satisfactory performance of thresher with the moisture levels of 9 to 13 per cent, feed rate of180kgh^{-1} and cylinder speed of 500 rpm.

El-Ashary *et al.* (2003) reported that the unthreshed sesame seed losses decreased by reducing the seed moisture content. Decrease of sesame seed moisture content from18.15 to 12.05 per cent tend to increasing threshing capacity from 2.23 to 3.06 th^{-1} from 2.95 to 6.87 th^{-1} and from 0.19 to 0.48 th^{-1} for complete, partial mechanized and conventional system respectively. Also the energy requirements decreased by reducing the seed moisture content.

Vejasit and Salokhe (2004) investigated the effect of machine-crop variables on the performance of an axial flow thresher for threshing soybean with four levels of drum speeds (400, 500, 600 and 700 rpm) which were equivalent to a peripheral velocity of 8.80, 10.99, 13.19 and 15.39 ms^{-1} respectively, three levels of feed rates (360, 540 and 720 kg (plant) h^{-1}, and three levels of moisture content 32.88, 22.77 and 14.34. The test results indicated that the threshing efficiency varied from 98 to 100 per cent. The damaged grain rate and grain loss rate are less than 1 per cent for 600 rpm cylinder speed, 540 kg (plant)h^{-1} feed rate with 14.34 per cent seed moisture content, whereas it is less than 1.5 per cent for 700 rpm, 720 kg (plant)h^{-1} with 22.8 per cent (w.b.). The best combination of feed rate and cylinder speed at 14.3 per cent moisture content was 600 to 700 rpm (13.2 to 15.4 ms^{-1}) and 720 kg (plant)h^{-1}.

Sinha *et al*. (2009) investigated the effect of moisture content, concave clearance and cylinder speed on visible injury, internal injury, germination percentage and threshing efficiency of chickpea seed crop with Three levels of moisture content (8, 10 and 12 per cent), three levels of cylinder peripheral speed (8.05, 8.94 and 13.42 ms^{-1}), three levels of concave clearance (12, 14 and 16 mm) and two cultivars namely BG -1088 and BG -1103. The result showed that the cylinder speed is the most critical factor of affecting visible and internal injury extent. Moisture content adversely affected the internal injury levels in threshed seed. The cylinder speed of 8.94 ms^{-1}, concave clearance of 14 mm and moisture content at 10 per cent yielded the seed of optimum quality with minimal visible and internal injury, and optimum threshing efficiency.

Goel *et al.* (2009) evaluated the low cost manual sunflower thresher with two types threshers (wire mesh type and perforated GI sheet type) and four levels of moisture content (13.84, 11.23, 10.50 and 8.38 per cent) dry basis for MSFH-17 variety of sunflower crop with different cub diameter ranging from 16-19 cm. They observed that the threshing capacity of the threshers increased with decrease in moisture content from 13.84 to 10.50 per cent, the mechanical damage decreased with decrease in seed moisture content and threshing efficiency increased with decrease in moisture content in all the treatments. The optimum seed moisture content was found to be 10.50 per cent for threshing of sunflower crop. The higher threshing capacity and lower cost of threshing were observed with wire mesh type thresher.

Radwan *et al.* (2009) developed and evaluated a tangential flow caraway crop thresher with four levels of rotor speeds (500, 560, 630, and 700 rpm), three levels of moisture contents (10.36, 11.84 and 13.72 per cent, and three levels of air speeds on sieves (4.8, 5.7 and 6.8 ms^{-1}), fixed hole diameter of sieves was 3 mm, feed rate was 540 kg h^{-1} and concave clearance was 15 mm. They obtained that the local threshing machine can be successfully used under the seed moisture content of 11.84 per cent, drum speed of 500 rpm and air speed of 4.8 ms^{-1} resulting seed losses of 2.2 per cent, threshing efficiency of 73.7 per cent, and criterion energy consumed 29.04 kW. $hton^{-1}$.

Bawatharani *et al.* (2012) investigated the effect of crop machine parameters in axial flow paddy thresher with three levels of grain moisture contents (26, 21 and 16 per cent), three levels of drum speeds (200, 300 and 400 rpm) and three levels of feed rates (120, 135, and 144 kgh^{-1}). Each treatment combinations were replicated thrice. They found that the unthreshed grain losses at 26 and 16 per cent moisture content decreased with increase in drum speed from 200 to 300 rpm at all the feed rate. At 21 per cent moisture content and 120 $kgh^{-1}$of feed rate, the unthreshed grain losses slightly increased with an increase in drum speed from 200 to 300 rpm. Higher values of the unthreshed grains obtained at higher moisture content.

Gbabo *et al.* (2013) evaluated a millet thresher with 135 kg sample of millet panicle was divided into of 45 kg samples each of 13, 15 and 17 per cent moisture content, 45 kg of millet panicles of each of the moisture content at 800, 700 and 600 rpm threshing cylinder speeds each. Each of the experiment was replicated three times and they concluded that the highest threshing efficiency of the machine was 63.20 per cent when millet was threshed at 13 per cent moisture content with a drum speed of 800 rpm, the highest machine cleaning efficiency of 62.7 per cent was achieved when the millet was threshed at 13 per cent moisture content at a drum speed of 800 rpm, the highest percentage loss of 51.68 per cent was obtained when the millet was threshed at 17 per cent moisture content with drum speed of 600 rpm .The millet thresher works more efficiently as the moisture content decreased and the threshing drum speed increases. Since the average threshing and cleaning efficiencies were about 63.0 and 62.7 per cent respectively, the optimum operating parameters of the thresher are demonstrated at 13 per cent moisture content (wet basis) and 800 rpm threshing drum speed.

Naveenkumar *et al.* (2013) investigated the efficiency of mechanical thresher over traditional method of threshing finger millet at three different moisture content (w.b.) levels of ragi (18 to 19, 13 to 15 and 10 per cent), two threshing drum speeds of 800 and 1000 rpm and three concave clearances of 4, 7 and 10mm. They concluded that the threshing efficiency increased with decrease in moisture content and increase in threshing drum speed. The important parameters which influence the threshing efficiency are mechanical damage, moisture content, threshing cylinder speed, feeding rate and concave clearance. They also reported that the moisture content of the ear-head plays a key role in threshing operation and seed quality.

Omale *et al.* (2015) developed a African yam bean thresher and evaluated with four levels of moisture content (10,11,12, and 13 per cent) and at cylinder speed of 467 rpm and fan speed of 1166 rpm, cylinder pulley of 225 mm and fan, motor pulley of 75 mm were selected and reported that the maximum threshing efficiency of 99.5 per cent was obtained at 10-13 per cent moisture content dry basis and the maximum cleaning efficiency of 96.19 per cent at a moisture content of 12 per cent dry basis.

Timothy Adesoye Adekanye *et al*. (2016) designed, fabricated and evaluated a soybean threshing machine which consisted mainly of the feeding assembly, the threshing unit, fan assembly and power transmission unit. The thresher was evaluated at different moisture contents (10, 16 and 22 per cent wet basis) and at different drum speeds (320, 385, 450 and 515 rpm) with constant mass input of 600g and constant concave clearance of 23 mm. The performance evaluation revealed the following.

1) The evaluation results indicated threshing efficiency of 98.96 to 99.88 per cent for the range of the variable of drum speed between 320 to 515 rpm and 99.73 to 99.29 per cent for the range of the variable of moisture content of 10 - 22 per cent (wet basis). The cleaning efficiency decreased (90.81 to 64.25 per cent) as the speed increased (320 to 515 rpm), at moisture contents of 10 and 22 per cent (wet basis).
2) The threshing efficiency tend to increase with the increase in drum speed and decrease with the increase in moisture content while cleaning efficiency increase as the cylinder speed decrease and as the moisture content.

3) High moisture content and low cylinder speed tend to reduce the percentage of damage seed, blown seed and seed loss respectively while low moisture content and high speed tends to increase the percentage of damage seed, blown seed and seed loss respectively. Moisture content state and impact on grain during threshing are paramount in determining crop mechanical damage (Allen and Watts, 1997; Dauda, 2001).
4) The efficiency of the soybean threshing machine is significantly affected by the dependent variables viz., cylinder speed and moisture content.
5) Spike tooth threshing drum tends to produce high threshing efficiency as seen from the results obtained (99.51 per cent) which compares well with the report by Peksen et al. (2013) for comparison of different beaters and concave for threshing chickpea.

IV. PERFORMANCE EVALUATION OF THRESHERS

Bansal *et al.* (1994) evaluated different sunflower threshers. Sunflower threshers based on axial flow designs were mostly used. It was concluded that sunflower should be threshed at a cylinder speed of 6.5 ms^{-1} with a feed rate of 1500–2000 kg (head)h^{-1} at a grain moisture content of 30 percent (w.b.).

El-Haddad (2000) developed a simplified design of threshing and winnowing machine suitable for sample holdings and performance evaluation results stated that the threshing efficiency increased with increasing of drum speed and decreasing of feed rate. The maximum threshing efficiency was 99.761 per cent at drum speed 21.25 ms^{-1} (1400 rpm), and feed rate 15 $kgmin^{-1}$. He added that the maximum amount of visible grain damage was 0.90 per cent at drum speed 21.25 $ms^{-1}$and feed rate of 15 kg min^{-1}.

Chandrakanthappa *et al.* (2001) used a rasp-bar type multi-crop thresher to thresh finger millet. The best results of threshing efficiency, 79.61 per cent and mechanical damage of 2.95 per cent were obtained at 4 mm concave clearance, 1000 rpm (1200 $mmin^{-1}$) thresher drum speed and grain moisture content of 10 per cent wet basis.

Naik *et al.* (2010) investigated the effect of moisture content, feed rate and cylinder peripheral speed on the performance of the three types of commercial paddy thresher operated by five hp electric motor (Thresher-I),10 hp electric motor (Thresher-II) and 35 hp MF-1035 tractors (Thresher-III). Thresher-I, II and III with optimum output capacities of 3.57 qh^{-1}, 4.21 $qh^{-1}$and 17.56 qh^{-1}gave threshing and cleaning efficiency in the range of 93.5 to 99.75 per cent and grain damage in the range of 0.5 to 6 per cent. The total cost of threshing per quintal, thresher (I, II and III) was found to be Rs. 13.16, Rs. 12.87 and Rs. 14.13 respectively. The output capacities in thresher (I, II, III) are 3.57 qh^{-1}, 4.21 qh^{-1} and 17.0 qh^{-1} respectively.

Munusamy *et al.* (2015) designed and developed a peg tooth type threshing cylinder for separating the florets from onion umbels further florets are conveyed to the thresher for separation of seeds from the florets. The performance of the unit was evaluated in terms of florets threshing efficiency, floret separation efficiency, percentage floret loss and seed damage at different feed rate, concave clearance and peripheral speed. They concluded that the peg tooth type thresher performance was good at 100 kgh^{-1} feed rate 6 mm concave clearance and 7 ms^{-1} peripheral speed.

Patil *et al.* (2016) developed a corn sheller and thresher basically consisted of a separate shelling chamber, threshing chamber, collecting tray and two hp electric motor. The arrangement of these parts is connected by belt and pulley mechanism. The weight was only 95 Kg and they concluded that the production rate for threshing operation was 300 kgh^{-1} and for shelling 300 kgh^{-1} then the germination rate for corn seeds threshed by the machine was found higher than conventional threshing.

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