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Impact of harvesting and threshing methods on seed quality-A review

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ABSTRACT

Harvesting and threshing operations contribute to overall post harvest losses. The speed of manual cutting operations risks significant crop losses due to delayed harvesting in developing countries. When harvest is delayed, shatter loss is the most-often mentioned cause of losses. Estimates of harvest losses range from 5 to 16% for rice and 8 to 18% for a range of different cereal crops. All of the cereal, oilseed and pulse crops have a narrow range of moistures for optimally-low harvest losses and high crop quality. The optimal moisture for harvest of all crops is nearly always too high to allow safe storage. Increased harvest mechanization can enable more timely harvest with lower losses, and would likely to create a gender shift in harvest workers. Training is essential for developing mechanized harvest operator skills. Most non-mechanized threshing systems have an inadequate means for separation and containment of harvested grains, oilseeds, and pulses. Threshing, separating and cleaning losses for well-trained combine operators can be very low, rice 0.3%, maize 0.4%, soybeans 0.75 - 1%, and wheat 1% of yield or less. Losses will go higher when the header is included but in general, rice should be less than 1.25 - 2.2%, maize less than 1.8%, soybeans less than 3%, and wheat less than 2% of yield in good standing crop.

Key words: Harvesting methods, Seed germination, Seedling vigour, Threshing methods.

The seed is the nucleus of farmer's production activities hence its quality should be guaranteed at all times (Owolade *et al.*, 2001). About 90% of all the food crops grown in the world are propagated by seeds. In any crop production systems, good quality seed inspires the confidence of farmers, because all other inputs will merely assist the seed to produce optimally.

India is a vast country, covering about 329 million hectare geographical area. About 166 million hectare is cultivated land and net area sown is about 142 million hectare (Kumar *et al.*, 2017). The population growth rate is much faster than the growth rate in food grain production in the country. In order to feed so much population, improved agricultural implements will have to be used to increase the output of farming operation in the country. To meet the requirement of food grain, scientific farming is necessary which includes introducing of high yielding varieties, development of irrigation facilities, efficient use of chemicals, fertilizers, insecticides etc. coupled with agricultural mechanization. Agricultural mechanization has resulted timeliness of operation, increased productivities of land apart from removal of drudgery of labour and also increase the economic return to farmer. Major components of agriculture mechanization, besides lift irrigation are tractor and associated farm equipment like tillers, disc harrows, seed drills, threshers, and increased usage of combine harvester in the country.

In developing countries, greater than 40 % of the losses occur during post harvest and processing operations (Gustavsson *et al.*, 2011). Post harvest operations are labour intensive and time consuming when carried out with manual labourers. Failure to complete these operations within the stipulated time may sharply reduce the seed quality. In India improved agricultural tools and equipment are estimated to contribute food production by saving in seeds (15-20%), fertilizers (15-20%), time (20-30%), and labour (20-30%) and also by increase in cropping intensity (5-20%), and productivity (10-15%) (Govindraj *et al.*, 2017). Harvesting and threshing losses are the first phase of post harvest losses. To fully comprehend these losses we need to review and understand the harvesting and threshing methods and operations used for major crops.

Harvesting: Crops are harvested after normal maturity with the objective to take out seed, straw, tubers etc. without much loss. It involves cutting / digging / picking, laying, gathering, curing, transport and stacking of the crop. In case of cereals like wheat and paddy the plants are straight and smooth and ears containing seeds are at the top whereas most of oilseed and pulse crops have branches, which create problems in harvesting by manual or mechanical means. As per Bureau

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of Indian Standards the cutting and conveying losses should not be more than 2 per cent.

Harvesting is considered as the first step in the seed supply chain and is a critical operation in deciding the overall crop quality. In the developing countries, crop harvesting is performed mainly manually using hand cutting tools such as sickle, knife, scythe, cutters. Almost all of the crop is harvested using combine harvesters in the developed countries (Kumar and Kalita, 2017).

Harvesting time and method (mechanical vs. manual) are two critical factors dictating the losses during the harvesting operations. A large amount of losses occurs before or during the harvesting operations, if it is not performed at adequate crop maturity and moisture content. Too early harvesting of crop at high moisture content increases the drying cost, making it susceptible to mold growth, insect infestation, and resulting in a high amount of broken seeds (Khan, 2010). However, leaving the matured crop un-harvested results in high shattering losses, exposure to birds and rodents attack, and losses due to natural calamities (rain, hailstorms etc.) (Baloch, 2010). In pea, faba bean and soybean substantial decline in viability and increasing rate of seedling abnormalities were observed when harvest was delayed beyond the optimal seed moisture content for harvest (Ellis *et al*., 1987). Sowing date and harvest method are important to maintain seed quality in soybean (Adam *et al*., 1989). Although, several studies had been done for improving the harvesting and handling of bean seeds (Hoki and Picket, 1973) and soybean seeds (Shreekant *et al*., 2002) to reduce seed damage and maintain seed quality

Choosing the method and equipment for harvesting depend on the type of product, planting and the climatic condition (Srivastava *et al*., 1990). Most of the harvesting is performed manually in the developing countries, which is a highly labour intensive and slow process. During peak harvesting season, even the India encounter labour shortages, which results in delays in the harvesting and subsequently large losses. According to a study conducted in Punjab, India, due to high shattering losses, the wheat harvesting losses were found increased by about 67% (2.5% from 1.5%) by delay in harvesting (Grover and Singh, 2013). Another post harvest loss study in India estimated a 10.3% increase (1.74% to 1.92%) in paddy harvesting losses due to delayed harvesting because of a lack in adequate harvesting equipment (Kannan *et al*., 2013).

Mechanical seed harvesting and conditioning are done to enhance quality and prepare seeds for planting. However, these processing operations subject seed to mechanical damage, which reduces seed quality due to internal and external injuries. Injury may range from breakage and bruising to cracks and internal physiological damage (Cicero *et al*., 1998). Mechanical damage is caused by abrasions and impacts as seeds pass through a series of machines from harvesting to bagging. These processes must be controlled to minimize damage during commercial seed production.

Methods and equipments for harvesting major crops: Harvesting of crops like paddy and soybean has to be done carefully as the matured seeds easily detach from the earheads/pods and, therefore, cannot be harvested by fast working tools or machines. Bengal gram, green gram, lentil are to be harvested at ground level. Oilseed crops pose different type of problems to engineers for mechanization of their harvesting. Safflower is a spiny crop and difficult to harvest even manually. In case of sunflower, harvesting is simpler as only flower heads are to be collected. In sesamum crops, pods containing seeds are attached to the main stem and they are mostly raised by broadcasting. This also needs gentle handling. Farmers follow different methods for harvesting of rapeseed/mustard and pigeon pea. Mostly, farmers harvest these crops at branch level, but small farmers harvest these crops at ground level. Harvesting of root crops involves digging, shaking to remove adhering soil, windrowing or stacking and picking. A good root crop harvester should give maximum recovery and cause minimum damage to pods or tubers.

Threshing: Seed processing is a fundamental component in any planned seed production programme, which aims at improving the seed characteristics (Araujo *et al*., 2008). The purpose of the threshing process is to detach the grain from the panicles. The process is achieved through rubbing, stripping, or impact action, or using a combination of these actions. The operation can be performed manually (trampling, beating), using animal power, or mechanical threshers. Manual threshing is the most common practice in the developing countries. Grain spillage, incomplete separation of the grain from chaff, grain breakage due to excessive striking, are some of the major reasons for losses during the threshing process (Shah, 2013).

Thresher is a machine to separate grains from the harvested crop and provide clean grain without much loss and damage. During threshing, seed loss in terms of broken seed, unthreshed seed, blown seed, spilled seed etc. should be minimum. Clean unbruised seed fetches good price in the market as well as it has long storage life.

Traditional threshing methods: Trampling of paddy under feet, beating shelves of rice or wheat crop on hard slant surface, beating crop with a flail, treading a layer of 15 to 20 cm thick harvested crop by a team of animals are traditional methods followed by farmers depending upon capacity, lot size and situation. Threshing by bullock treading is practiced on large scale in the country but it is also time consuming and involves drudgery. Tractor in many places is now used in place of animals for treading. Introduction of animal drawn thresher reduced the drudgery of the operator and gave comparatively higher output per unit time. In all above methods the threshed materials are subjected to winnowing either in natural wind flow or blast from winnowing fan for separation of grain from straw.

Threshing methods impact on seed quality: Methods of threshing influence seed quality in terms of germination and vigour (Kausal *et al*., 1992). Shelar (2002) reported that, the vigour index of soybean seed threshed by stick beating and processed manually was significantly higher than that of seeds threshed and processed by machine irrespective of varieties. The different threshing methods produces breaks, cracks, bruises and abrasions in seeds which in turn results in abnormal seedlings of questionable planting value. It is obvious from the available information that mechanical injury to seed not only reduces production of normal seedlings but also decreases the storage potential of damaged seed that apparently would have produced normal seedlings prior to storage. The obvious manifestation of physical seed damage include fractures of the radical or bruising of the cotyledons which are difficult to detect under the seed coat. In extreme instances damage to the radical can result in abnormal seedlings which fail to germinate. Any damage to the cotyledons is also concerns because it retards translocation of essential nutrients to growing embryonic axis which culminates in delayed seedling growth.

Mechanical and physical properties of seeds are necessary in designing, handling and processing equipment for them. The resistance to impact, among other mechanical and physical properties, play a very important role in the design of threshers, equipment for loading and unloading, storage structures, harvesting machines, drying equipment, conveyors, spouting and free-fall dropping equipment (Baryeh, 2002; Khazaei *et al*., 2008).

Soybean seed being inherently a weak structure is more prone to mechanical thrust which increases its deterioration (Tekrony *et al*., 1987; Gagare *et al*., 2014; Kuchlan *et al*., 2017). El-Abady *et al.* (2012) evaluated the effect of different threshing methods i.e., hand, beating by stick and mechanical on some soybean cultivars i.e., Giza 21, Giza 35 and Giza 111 and kept under ambient storage conditions and then tested for seed quality. They found that threshing by hand resulted in higher germination per cent and seedling vigour than the other two methods at all stages of storage.

Mechanical damage of bean seeds is of great importance for seed producers, farmers and food processors (Bay *et al*., 1995) and is considered the most common reason for poor seed quality in large seeded legumes and this occurs when seeds are threshed at unsuitable seed moisture content and at high drum speed (Greven *et al*., 2001). Mechanical damage is a seed quality factor that may affect the worth of soybean seed lots (Luedders and Burris, 1979). Gagre *et al*. (2014) reported that of soybean seed threshed by stick beating recorded lower mechanical damage percent than other two threshing methods viz., multi crop thresher and combine harvester irrespective of varieties (Table 1). Soesarsand and Copeland, 1974 also observed increase in percentage of the abnormal and dead seed in mechanical damaged bean seeds.

Ponmani, (2015) conducted the experiment to evaluate the various threshing methods for barnyard millet, such as manual beating with pliable stick, threshing with tractor treading, threshing using paddy thresher. Among the three methods of threshing studied, the threshing using paddy thresher showed higher threshing efficiency (69.2 per cent) with minimum time. Seed quality parameters *viz*., germination (77 per cent), vigour index (1701) also maximum with the seeds threshed by paddy thresher (Table 2).

Goli *et al*., 2016 studied the effects of impact velocities (IV), number of impact loadings (NL), and time (T) on percentage of seed damage and percentage of loss in germination to soybean seeds. Increasing the impact velocities from 12.4 to 22 m/s (IV_1=12.4, IV_2=16, IV_3=22 ms^{-1}) and number of impact loading from 1 to 3 times (NL1: one brunt, NL2: two brunt and NL3: three brunt) and time to three months (T_1: when impact loading to seed, T_2: after 45 days and T_3: after 3 months) caused an increase in percentage of seed damage from 2.76 to 24.29% and increase in percentage of loss in germination from 28 to 96, respectively.

Sinha and Pandita, 2002 threshed Okra cv. Pusa A-4 seeds by manual, tractor treading, de-awner (400 rpm) and Pullman thresher (650 rpm) gave 54.05, 53.8, 46.7 and 51.30 per cent seed recovery and germination of 92.6, 88.0, 78.0 and 87.0 per cent respectively. The seedling dry weight and vigour index was also significantly higher in manually

Table 1: Effect of varieties X threshing methods on mechanical damage of soybean seed.

Varieties	Mechanical damage (%)		
	Stick beating	Multi crop thresher	Combine harvester
JS -335	9.75	13.25	16.67
JS -9305	8.88	12.13	14.90
JS -9560	10.46	13.71	18.17
SE +		0.175	
CD at 5%		0.490	

(Source: Gagre *et al.,* 2014)

Table 2: Effect of threshing method on germination and seedling vigour of Barnyard millet.

Threshing method	Fresh seeds					45 days old seeds				
	Germination (per cent)	Root length (cm)	Shoot length (cm)	Dry matter production (g seedling^{-10})	Vigour index	Germination (per cent)	Root length (cm)	Shoot length (cm)	Dry matter production (g seedling^{-10})	Vigour index
Manual threshing	35 (36.27)*	13.5	9.0	0.015	788	76 (60.67)	13.2	9.2	0.016	1702
Tractor treading	30 (33.21)*	13.0	8.0	0.012	630	75 (60.00)	12.7	8.5	0.013	1590
Mechanical Threshing	36 (36.87)*	14.0	9.5	0.013	846	77 (61.34)	13.5	8.6	0.016	1701
Mean	33 (35.06)*	13.5	8.8	0.013	755	76 (60.67)	13.1	8.8	0.015	1664
SEd	0.73	0.19	0.24	0.0002	17.05	1.438	0.34	0.17	0.0004	54.98
CD(P=0.05)	2.01**	0.52*	0.66**	0.0006**	47.32 **	NS	NS	0.45*	0.0012**	NS

(Source: Ponmani and Masilamani, 2015)

threshed seeds. Mechanical damage to seed was higher with tractor treading (Table 3).

Masilamani *et al*. (2015) conducted an experiment to find out the influence of different methods of extraction of seed from pods of *Albizia lebbeck* viz., Splitting by hand, beating with plyable stick and threshing with paddy thresher and man-hour requirements, cost of extraction, seed recovery, viability, germination and seedling vigour was calculated. It was found that results on viability test revealed that there was no significant difference on viability (97.5 %) between the extraction methods. Seeds extracted through commercial paddy thresher gave maximum germination per cent and lesser cost of extraction for 50 kg of *Albizzia lebbeck* pods viz., 13 % and Rs. 87.5/- respectively, followed by beating with plyable stick (9 % and Rs. 187/-) and splitting with hand (5 % and Rs. 500/-) respectively.

The amaranth seeds have embryos that encircle the perisperm in one plane (Irving *et al*., 1981). Therefore is vulnerable to mechanically induced injury during combine harvesting which increases its deterioration. Krishnan *et al*. (1994) observed that the percentage of normal grain amaranth seedlings decreased and that of abnormal seedlings increased as threshing cylinder speed increased from 8.1 to 30.7 ms^{-1}.Although injury to hand-harvested seeds or seeds threshed at 8.1 ms^{-1} was not apparent, scanning electron micrographs of seeds threshed at 12.8 or 22.4 ms^{-1} revealed damage to the seed coat and the endosperm. Damage extended to the embryo when threshing cylinder speed was increased to 30.7 ms^{-1}.

Threshing methods and moisture content impact on seed quality: The recommended threshing moisture for sorghum seeds is around 14% - 16 % and therefore, threshing above this moisture content results in seed quality deterioration (WFP, 2012). The mechanical damage to the seed during threshing varies depending on the genetics of the variety. It has been reported that, seed hardness plays an important role in seed processing and vitreous endosperm variety pose breakage resistance (Felker and Paulis, 1993). Dharmaputra *et al*. (2012) studied post harvest quality improvement of sorghum seed and showed that method of threshing of sorghum seeds have significant effects on seed damage in terms of cracked and broken seeds and germination. The percentage of damaged seed of sorghum threshed using a wooden stick was higher and significantly different from that threshed with a paddy thresher. Also, the percentage of seed germination was higher in sorghum threshed using paddy thresher (93.3%) and significantly different from that of sorghum threshed using a wooden stick (91.04%).

Singh and Singh, (1981) investigated the effect of moisture content, threshing speed and length of storage period after threshing, on threshing performance and quality of two varieties of soybean. It was found that unthreshed

Table 3: Effect of threshing methods on seed quality in Okra cv. Pusa A-4.

Treatment	Speed (rpm)	Recovery (%)	Visible cracks(%)	Germination (%)			Dry weight (g/10 seedlings)	Vigour Index
				Normal	Abnormal	Dead		
Manual Threshing	-	54.05	0.00	92.6	2.3	5.0	0.2784	25.79
De-awner Threshing	400	53.80	0.60	88.0	2.7	9.3	0.2781	24.45
Tractor Threshing	-	46.70	1.13	78.0	4.0	18.0	0.2503	19.51
Pull-man Threshing	650	51.30	0.32	87.0	3.6	9.3	0.2683	23.34
C.D. at 5 % level		-	0.15	3.9	NS	3.8	0.012	1.51

(Source: Sinha and Pandita, 2002)

grain increased with an increase in pod moisture content whereas grain damage decreased with an increase in grain moisture content. The percentage unthreshed grain decreased with an increase in cylinder speed for all pod moisture contents. Grain damage increased with increase in cylinder speed for all grain moisture contents. The variety Ankur was a little harder to thresh and was more resistant to damage than PK 71-21. Both storage time and threshing speed had only a small effect on the germination percentage of both varieties.

Kumar *et al.* (2017) reported that amount of unthreshed grain and grain breakage is significantly affected by moisture content and cylinder speed of combine harvester. Percentage of unthreshed grain and grain breakage were increased with increasing forward speed from 3.25 to 4.05 km/hr and decreasing crop moisture content from 20 – 16 % due to less space between cylinder and concave clearance and with increasing drum speed. This is because increasing the speed increased frequency of impact between the crop and the threshing members and hence, rubbing of the pods were more severe.

Kidney beans are more susceptible to breakage under impact loading during harvesting and processing. This problem limited the mechanical harvesting. Mechanical damage decreased the commercial values and the biological values of seeds. Khazaei (2008) studied the relationship impact velocity (at 5, 7.5, 10, and 12 m/s) and beans moisture content (at 5, 10, 15 and 20% wet basis) on percentage of physically damaged beans. The results showed that increasing the impact velocity from 5 to 12 m/s caused an increase in the mean percent of physical damages from 3.25 to 37.5%. With increasing the moisture content from 5 to 15%, the mean values of percentage of damaged beans decreased by 1.4 times. However, with higher increase in the moisture content from 15 to 20%, the mean values of physically damaged beans showed a non-significant increasing trend.

Sinha *et al.* (2009) studied the effect of moisture content, concave clearance and cylinder speed on visible injury, internal injury, germination percentage and threshing efficiency of chickpea seed crop. The result showed that, seeds that were threshed at various moisture contents had significant difference in internal injury. Cylinder speed at 8.94 m/s, concave clearance at 14 mm and moisture content at 10% resulted in seeds of minimal visible and internal injury and optimum threshing efficiency. Similarly, Koyuncu *et al.* (2007) found that, the chickpea varieties varied significantly in threshing efficiency depending on the physical characteristics and mechanical specifications among varieties. Such adverse effects on seed quality may affect sorghum seeds if processed with similar machines.

Kavak *et al.* (2012) reported that, seed moisture content and threshing methods significantly affected the quality of bean seeds and seeds threshed at below 14% seed moisture content, had higher incidence of cracked seed coats and had the lowest percentage of normal seedling. Other researchers have also shown that, too much moisture content can be as damaging to seed quality just as too little moisture. Saeidirad and Javad (2011) evaluated the effect of thresher variables including seed moisture content in cumin and found that moisture content significantly affects seed damage and germination. The results showed that as moisture content increased from 7% to 13%, separated and damaged seed decreased from 92.8% to 90.4% and from 10.1% to 7.6%, respectively.

The threshing section on combine harvester or thresher machine affects grain and stalk separation performance. Saeidirad *et al.* (2013) conducted the study with view to optimize important operational and crop parameters influencing the threshing of sorghum. In this research, the effects of cylinder speed with four levels (13, 17, 21 and 25 m/s), concave clearance (5, 10 and 15 mm) and feed rate (420, 500 and 590 kg/h) were investigated on un-separated seed percentage, damaged seed percentage and germination. The result showed that concave clearance created a significant effect on damaged seed percentage. The increase of concave clearance from 5 to 15 mm caused that un-separated seed weight percentage increased from 0.69% to 0.78%, and damaged seed rate decreased from 13.01% to 11.01% (Table 4).

Harvesting and threshing by combine harvester impact on seed quality: The combine harvester, or simply combine, is a machine that "combines" the tasks of harvesting, threshing and cleaning the harvested produce. The desired result is the seed (of rice, corn, soybean, black gram etc.). Whether mechanical threshing is performed by a field

Table 4: Means comparison of adjectives in different variations in sorghum.

Factors	Factor levels	Un separated seeds (%)	Damaged seeds (%)	Germination (%)
Cylinder speed (m/s)	13	1.82 a	4.2 a	75.96 a
	17	0.66 b	5.52 a	76.03 a
	21	0.22 c	14.30 b	72.09 b
	25	0.16 c	24.91c	76.23 a
Concave clearance (mm)	5	0.69 a	130.1 a	73.79 a
	10	0.67 a	12.68 a	75.51 a
	15	0.78 a	11.01 b	75.93 a
Feed rate (kg/h/m)	420	0.72 a	12.11 a	74.02 a
	500	0.58 a	11.99 a	76.28 a
	590	0.84 a	12.60 a	74.93 a

(Source: Saeidirad *et al.,* 2013)

thresher or a combine, the peripheral velocity of the cylinder or rotor and the tightness of clearance to the fixed concave is critical. Higher peripheral threshing velocity is needed as crop moisture increases. As crops dry, crop material is easier to thresh and peripheral velocity should be reduced. Outer hull, pericarp, or seed coat of seed is usually soft when at high moisture; thus, excessive peripheral velocity with too close of concave clearance will also be detrimental to quality of threshed grains. (Alizadeh and Khodabakhshipour, 2010).

Combine harvesters work best with well-drained fields that are somewhat level and with a field layout that minimizes the number of turns in a field (IRRI, 2015). Operators must have sufficient training to have an understanding of each of the unit processes occuring within the combine – namely cutting or stripping, gathering and uniform conveying (reel position and speed setting), cylinder or rotor threshing (concave clearance and threshing speed adjustments), separation with rotor or with straw walkers, aspiration of air (fan speed setting) to blow out chaff, mold spores and light particles, sieve opening and shaking allowing separation by density and size of threshed kernels. In addition, the operator must maintain ground speed slow enough to provide ample time for uniform threshing and good separation (Fig 1). Driving overly fast is one of the most common causes of higher-than-necessary combine losses (Paulsen *et al.*, 2014).

Andrews *et al*. (1993) studied the effects of operational parameters in rice combine harvesting on crop quality and losses. It was demonstrated that feeding rate is the determining factor in rates of loss. Shieh and McDonald (1982) discovered whether there was any significant difference between shelled or whole ear harvesting in the germination ability of two randomly selected hybrid seed fractions. The results over several years of experiments indicate that it may prove necessary to elaborate a new system of field quality control criteria, allowing shelled harvesting as well as ear harvesting in the case of seed production of corn. Mounsey *et al*. (2002) evaluated the effect of combine harvesting on seed quality, they reported higher seed

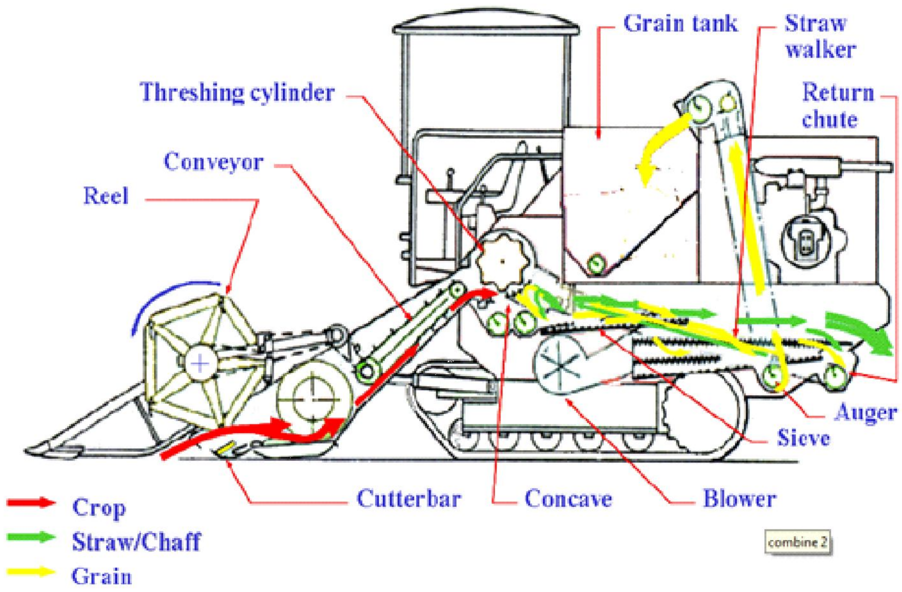

Fig 1: Schematic of flow in a combine harvester.

(Source: IRRI, 2015)

shedding losses for harvesting at 20% moisture content, and recommended shelled harvesting as an alternative solution, rather than the traditional harvesting of whole ears in maize. Varga *et al*., 2012 studied the relationship between seed harvesting method and seed physiological quality (germination and vigour) of eight Pioneer Hi-Bred maize hybrids were evaluated immediately after harvesting and a year later. They reported that the higher germination percentage and lower abnormal seedling percentage was observed after manual shelling than after mechanical shelling. The seed vigour of three of the hybrids was highest when maize seeds were harvested shelled rather than on the ear but the difference was not significant.

Extensive range of crops from oilseeds, grass and clover seeds through to large faba beans are mechanically harvested with combines. There are five losses relating to the combining of the grain: a) shatter loss: grain laying on the ground or out of reach of the cutter bar, b) cutter bar loss: grain lost due to rough handling by the cutter bar, c) threshing loss: grain Lost out the rear of the combine in the from of unthreshed heads, d) separating loss: grain lost out the rear of the combine in the from of threshed grain and. e) cleaning loss: loss in value of the crop due to the presence of foreign matter in the grain tank (Hunt, 2001). Small grains and oilseed rape harvesting losses, which occur during cutting, separation, cleaning and shaking, reach 5–10%; cutting and separation processes account for 80–90% of the total harvesting losses. (Domeika *et al*. 2008).

The platform losses increased with increasing operational speed and decreasing moisture content. Increasing in speed from 1.13 to 1.68 km/h caused the total loss in oil seeds harvest to reach from 12.34 to 17.08, from 10.58 to 15.48, and 10.92 to 10.16, respectively in moisture content of 12, 15 and 19 % (Kholief *et al*., 2009). Lotfy *et al*. (2002) found that by using combine harvester, increasing forward speed from 1.8 to 4.8 km/h increased platform losses from 3.7 to 9.9, 4.10 to 10.2, 4.40 to 10.80 and 9.8 to 14.9% at seed moisture content of 22.6, 18.4, 15.3 and 11.2 % respectively.

Table 5: Effect of harvesting methods on germination –ADT 36.

Method of harvest	Seed germination (%) Storage period (months)				
	Fresh	**3**	**6**	**9**	**12**
Manual	94.52	93.41	90.12	87.51	85.21
Combine	94.32	92.28	89.52	86.23	83.28

(Source: Masilamani and Tajuddin, 2012).

Table 6: Effect of harvesting methods on germination –BPT 204.

Method of harvest	Seed germination (%) Storage period (months)				
	Fresh	**3**	**6**	**9**	**12**
Manual	91.67	89.31	86.67	86.00	83.51
Combine	91.33	87.44	84.62	83.60	82.00

(Source: Masilamani and Tajuddin, 2012).

The performance of a wheat plot combine harvester was evaluated at three levels of moisture content and operational speed, on the basis of total losses, grain breakage, performance and threshing efficiency, the speed of 1.5 km/h gave better results at 9.16 % moisture content than the other two speeds (1 and 2 km/h) (Patel and varshney, 2007).

Masilamani and Tajuddin, (2012) studied the effect of combine harvesting on germination of rice varieties viz., ADT 36 and BPT 5204 and storability of seeds were evaluated under ambient temperature for 12 months. It was found that the seeds harvested by combine maintained 83 per cent and 82 per cent germination in respect of ADT 36 and BPT 5204 respectively upto 12 months (Table 5 and Table 6).

Rod *et al*. (2013) investigated the berseem clover seed losses due to seed moisture content and the speed of combine harvester at seed harvest time with three seed moisture contents (10, 15 and 20%) and three combine working speeds (1, 2 and 2.5 km/h). They found that the interaction between speed and seed moisture content on platform and thresher was significant. Reduction of seed moisture content from 20% to 10%, seed losses on platform increased from 4.61% to 8.11%. Interaction between combine working speed and seed moisture content showed 4.53% (65.98 kg/ha) losses where combine working speed was 1 km/h with 20% seed moisture content and the highest was 11.66% (169.2 kg/ha) using 2.5 km/h speed and 10% moisture content. Finally combine working speed of 2 km/h and 15% seed moisture content were suitable for harvesting berseem clover seed.

Masilamani *et al*. (2017) studied the effect of different harvesting and threshing methods on mechanical damage, germination and seedling vigour of sunn hemp. The results revealed that the seeds harvested and threshed by manual method recorded lowest mechanical damage of 3.0 % followed by combine harvesting (3.8 %) and also these two methods maintained the initial germination per cent of 92 and 89, respectively but the combine harvesting recorded the highest seedling vigour of 1818 than other methods. Thus, they inferred that combine harvester can be recommended for harvesting the sunn hemp crop (Table 7).

Effect of machine-crop variables on seed quality: Vejasit and Salokhe, (2006) studied the effect of machine-crop variables on the performance an axial flow thresher for threshing soybean. Test results indicated that the threshing efficiency varied from 98 to 100%. Damaged grain and grain loss were less than 1% for 600 rpm cylinder speeds, 540 kg (plant)/h feed rate with 14.3% seed moisture content, whereas it was less than 1.5% for 700 rpm, 720 kg (plant)/h with 22.8 % (w.b.). The best combination of feed rate and cylinder speed at 14.3 % moisture content was 600 to 700 rpm (13.2 to 15.4 m/s) and 720 kg (plant)/h. Rani *et al*. (2001) studied the effect of moisture content and cylinder speed on threshing chickpea. They reported that maximum threshing efficiency

Table 7: Effect of harvesting and threshing methods on mechanical damage, germination and initial seedling vigour of sunn hemp.

Treatment	Mechanical damage (%)	Germination (%)	Root length (cm)	Shoot length (cm)	Drymatter production (g seedlings^{-10})	Vigour Index
Manual harvesting and manual threshing	3.0 (9.98)	92 (73.57)	4.3	14.2	0.197	1692
Manual harvesting and mechanical threshing	4.8 (12.66)	83 (65.65)	4.7	14.8	0.167	1606
Manual harvesting and threshing by tractor treading	4.0 (11.54)	89 (70.63)	4.9	13.8	0.176	1667
Harvesting and threshing by combine	3.8 (11.24)	89 (70.63)	5.3	15.1	0.182	1818
Mean	3.9 (11.39)	88 (69.76)	4.8	14.5	0.181	1696
SEd	0.5831	3.1491	0.5879	0.3845	0.0066	102.8748
CD (P=0.05)	1.2361	NS	NS	0.8377	0.0145	NS

(Source: Masilamani *et al.*, 2017).

Table 8: Effect of different harvesting and threshing methods on Germination (%) and Vigour index of different rice varieties.

Treatment (T)	Germination (%)				Vigour index			
Varieties(V)	T_1	T_2	T_3	Mean	T_1	T_2	T_3	Mean
CO51 (V1)	96 (79.41)	93 (75.06)	95 (78.19)	94.7 (87.11)	3251	2965	3057	3091
CR1009 Sub 1 (V2)	94 (76.96)	90 (72.05)	91 (72.88)	91.7 (74.18)	3519	3121	3255	3298
Improved White Ponni(V3)	97 (80.64)	91 (72.88)	94 (77.87)	94.0 (77.87)	3317	2967	3087	3124
Mean	95.7 (80.26)	91.3 (73.90)	93.3 (76.00)	93.4 (76.72)	3362	3017	3133	3171
SEd CD (P=0.05)	V	T		V×T	V	T		V×T
	2.764	2.764		4.787	87.19	87.19		151.02
	NS	NS		NS	NS	178.90		NS

T_1 - Manual harvesting and threshing, T_2 - Manual harvesting and mechanical threshing, T_3 - Combine harvesting.
(Source: Govindraj *et al.*, 2017)

was 97.2% at 8.9% seed moisture content with 10.1 m/s cylinder speed. Ajav and Adejumo, (2005) evaluated effects of moisture content, concave clearance, cylinder speed and feed rate on threshing performance and damaged okra seeds. They reported that moisture content had a significant effect on threshing performance and seed germination. The effect of cylinder speed was significant on threshing performance alone.

Lashgari *et al*. (2008) studied the effects of forward speed, cylinder rotation and clearance between combine's cylinder and concave on wheat kernel breakage and seed germination. Three levels of adjustments for each of the variables, namely 1.2, 1.8 and 2.5 km/h for forward speed, 800, 900, 1000 rpm for cylinder rotation and 15, 20 and 25 mm for the clearance between cylinder and concave were constituted the variables. The results indicated an increase in kernel breakage and a decrease in seed germination due to decrease in forward speed, increase in cylinder rotation and decrease in clearance between cylinder and concave. The interaction between forward speed and cylinder rotation indicated a least kernel breakage of 5.47% along with the most seed germination of 96.61% arising from a forward speed of 1.8 km/h together with cylinder rotation of 800 rpm. Also, an interaction between cylinder rotation and concave clearance indicated a least kernel breakage of 5.38% at 900 rpm and 25 mm, respectively. Thus, the most suitable adjustments for 955 model John Deere combine in the studied area would be 800 and/or 900 rpm, 1.8 km/h and 25 mm for cylinder rotation, forward speed and cylinder concave clearance, respectively.

Govindaraj *et al*. (2017) conducted the experiment to find out the influence of harvesting and threshing methods on seed quality of rice varieties viz., CR1009 Sub1, IW Ponni and CO51. The treatments are manual harvesting and manual threshing, manual harvesting and mechanical threshing (axial flow thresher) and combine harvesting (with pneumatic wheel). The results revealed that rice seed harvested and threshed through manual method or by combine harvesting method with minimum mechanical damage did not affect the germination and seedling vigour irrespective of the varieties (Table 8).

CONCLUSION

To avoid losses due to delayed harvest, steps may be needed to put in place systems for harvest mechanization with a training-education component to provide training to operate newer mechanized harvest equipment and systems. Therefore it is hereby recommended that the combine harvester is the successful answer to harvest crop since fast and efficient method of harvesting is the immediate need of farmers due to shortage of manual labour and multi-crop threshers are ideal for threshing major cereals, oilseeds and pulses. These equipments help in minimizing losses and maintaining the quality of the produce by proper timing of threshing and machine adjustment.

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