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Factors Causing Low Head Rice Recovery in Combine-Harvested Paddy

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Abstract: For paddy harvesting, old conventional wheat combine harvesters induce impact threshing forces on kernels, which result in a higher rice breakage during milling. This study was designed to identify the causes of low head rice recovery in combine-harvested Super Basmati rice grown in the Punjab province of Pakistan. Data were collected from 32 fields evaluating four types of conventional and four types of head-feeding combine harvesters. The quality of milled rice of combine-harvested paddy was compared with manually-harvested paddy. The manual harvesting and threshing gave the highest head rice recovery (64.24%) followed by head-feeding combine harvesters (62.38%). Conventional combine harvesters gave the lowest head rice recovery (58.23%). Manual harvesting method gave more shattering losses (up to 13%) due to many crop handling operations. Conventional combine harvesters gave 12% shattering losses and 7% threshing losses. Similarly, head-feeding combine harvesters gave 3.5% shattering losses and 1.5% threshing losses. Crop health was identified as an important factor yielding low head rice recovery. Healthy crop gave better head rice recovery than the medium or weak crop. Other factors yielding low head rice recovery included crop status (standing or lodged), crop moisture, machine parameters (forward speed and cylinder speed) and operator's skill. Operator's skill was perhaps the most critical factor to control rice breakage during combine harvesting of paddy crop. Head-feeding combine harvesters produced lesser broken rice than the old European wheat combine harvesters and are therefore more viable option for paddy harvesting.

Key words: Paddy harvesting methods; Conventional combine harvesters; Head-feeding combine harvesters; Crop health; Head rice recovery.

INTRODUCTION

Rice is ranked as second staple food after wheat in Pakistan. Rice was grown on an area of 2,789 thousand ha, during the year 2013-14, with a total production of 6,789 thousand tonnes. Basmati rice is one of the major export commodities of the country and is a major source of foreign exchange earnings after cotton (Ministry of Finance, 2014).

Paddy harvesting and threshing operations are very crucial and influential to control rice quality, quantity and production cost. Traditionally, paddy is harvested manually in the country, which is a labour-intensive practice. Consequently, labour shortage and increased labour wages cause delay in harvesting (Khan and Salim, 2005). Paddy harvesting time in terms of crop maturity has a significant effect on head rice yield or recovery (Malik *et al*., 1981; Ali *et al*., 1990; Surek and Beser, 1998; Khan and Salim, 2005; Hossain *et al*., 2009). Time slot between rice harvesting and wheat sowing in the rice-wheat cropping system of the Punjab is limited up to 2-3 weeks. Therefore, mechanised harvesting is a practical solution to ensure timely harvesting of rice crop.

Combine harvesters greatly help in labour and time saving. However, it has been noticed that the use of combine harvesters causes negative impact on the quantity and quality of paddy grains besides causing soil compaction, which affects the profitability of the crop (Personal Communication, 2012). This concern has also been reported in earlier studies (Ali *et al*., 1990; Hassan *et al*., 1994; Helmy *et al*., 1995). In the Punjab province of Pakistan, more than 60% paddy is harvested by old and reconditioned European wheat combine harvesters fitted with rice threshing kits (called as conventional combine harvesters) by poorly trained operators (Khan and Salim, 2005), where a sizeable amount of grain loss/damage occurs. Most losses are caused by improper adjustment of machines with respect to crop conditions (Griffin, 1976). The price of paddy is directly linked with head rice yield, which is defined as the milked kernels not less than three-fourth of the whole grain (Sharma and Kunze, 1982; Sabir *et al*., 1990). Crop age, ripening conditions, harvesting moisture content and

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postharvest handling are the major factors that influence grain breakage during milling (Sabir *et al*., 1990).

Despite benefits of combine harvesters, the rice millers were complaining about broken rice in combine-harvested paddy, resulting in low head rice recovery. On the other hand, the owners of combine harvesters were not ready to accept the concerns of rice millers that combine harvesters break paddy grains. Therefore, the factors, causing low head rice recovery as a result of using combine harvesters, were needed to be studied. Moreover, it has to be ascertained whether or not the operators are properly trained to operate combine harvesters especially for long grain Basmati rice. No study was conducted so far to evaluate the performance of combine harvesters for head rice recovery. Therefore, this study has been designed to identify causes of low head rice recovery in combine-harvested Basmati rice in the Punjab.

MATERIALS AND METHODS

Data collection: Data were collected on combine-harvested paddy variety 'Super Basmati' from four districts of the Punjab province: Gujranwala, Sheikhupura, Lahore and Sialkot, in collaboration with PARC Rice Research Institute, Kala Shah Kaku, Lahore; Guard (Pvt.) Ltd., Lahore and Engro (Pvt.) Ltd., Lahore. Data were collected on three predominant paddy harvesting methods used in the Punjab: manual harvesting and threshing; conventional combine harvesting and modern head-feeding combine harvesting (Japanese combine harvesters). Four types of conventional and four types of head-feeding combine harvesters were used to collect data during rice harvesting seasons of 2012 and 2013. Data were collected from 32 fields, ranging from 1 to 5 ha area. Both, fields and combine harvesters, were selected randomly. Three replications of grain samples were collected from each field. Harvesting losses were determined in each field for each combine harvester. An area of 2 m^2 was harvested manually from each field to compare combine-harvested paddy results with the manual harvesting method. Data were collected for both standing and semi-lodged crops; however, data were not collected from fully lodged crop because lodged crop was difficult to harvest, using a combine harvester. About, 5 kg paddy sample was collected from each field for determining head rice recovery (yield). Each farmer was interviewed before the test about variety, sowing method and field practices. Field size and meteorological data were measured before the test. Moisture content of standing and harvested crop was measured, using "Riceter" Grain Moisture Tester (Ket Electrical Laboratory, Tokyo, Japan). For collecting shattering losses, a bar square (1×1 m^2) was used (Fig. 1) and three measurements were taken from each field. For threshing losses, a big cloth bag (Fig. 2) was attached behind the combine harvester for a certain area and calculated threshing losses. Before collecting data, crop health was examined by four rice experts from Rice Research Institute, Kala Shah Kaku, who determined crop health based on crop stand, paddy kernel size, weight, colour and other factors. After evaluation by the experts, each sampled crop was categorised as healthy, medium and weak. Travel speeds and threshing cylinder speeds were also measured in each field.

Fig. 1: Collection of shattering losses using 1×1 m^2 bar square.

Fig. 2: Collection of threshing losses of combine harvesters.

Sample preparation: Paddy samples were sun dried to achieve the desired level of moisture content of 11-13% recommended for paddy storage and processing. Paddy samples were processed for de-husking, brown rice, polished rice, broken rice and head rice yield at the Laboratory of Agricultural and Biological Engineering Institute, National Agricultural Research Centre, Islamabad. Each sample was analysed in three replications to avoid any sources of error during the milling process.

Sample milling: Three replications of 200 g paddy were taken for combine-harvested and manually-harvested paddy samples. Paddy was de-husked, using a rubber roller type de-husker (Colombini Sergo & C. SAS, Italy). After getting brown rice, these were milled for 30 seconds, using a friction type polishing mill (Colombini Sergo & C. SAS, Italy). The total weight of the milled rice was measured to determine the percent loss in weight of brown rice on milling. Broken grains were separated, using indent cylinder machine, at 12º angle (5XW-1 Beijing Xide Agriculture Technology, Co., Ltd., China). Percentage of head rice yield was calculated as determined by Sabir *et al*. (1990) and Bawatharani *et al*. (2014). About, 3 kg paddy sample, from each field, was also milled at village level shellers (one step de-husking and polishing process) to compare the results with laboratory method.

RESULTS AND DISCUSSION

Machine parameters and skill of operator: Main specifications of combine harvesters, used in this study, have been shown in Table 1. Conventional combine harvesters have more cutting width ranging from 2.4 to 4.6 m depending on the header size, whereas, the cutting width of head-feeding combine harvesters was only 1.44 m (four rows). Therefore, the field capacity of head-feeding combine harvesters was lower than the conventional combine harvesters (Table 1). In this study, all combine harvesters were operated at operators' set forward and cylinder speeds to see the real damage occurring during paddy harvesting. The measured cylinder speed of combine harvesters ranged from 500-900 rpm and the travel speed ranged from 2.0 to 3.5 km h^{-1} in all tests.

Head rice recovery is significantly influenced by the skill of the operator, forward speed, feed rate and threshing drum speed for conventional combine harvesters. It was realised that combine operators used different forward and threshing cylinder speeds irrespective of the crop condition, which are major causes of low head rice recovery. Higher threshing cylinder speed has a substantial effect on the damage of paddy kernels (Sabir *et al*., 1990; Mohtasebi *et al*., 2006; Bawatharani *et al*., 2014). Feliz *et al*. (2005) reported that the percentage of damaged kernel for 550, 850, and 1000 rpm of cylinder speed was 1.2, 4.0 and 9.0% respectively, showing increased threshing losses with the increase in threshing cylinder speed. Griffin (1976) reported that most losses for paddy harvesting occurred due to improper adjustment of machine with respect to crop conditions and improper cutting speed. Sabir *et al*. (1990) reported that decrease in head rice recovery occurred with the increase in cylinder speed at a specific feed rate level. With increased cylinder speed, the impact blow of cylinder on paddy develops cracks in the paddy grains. For minimum threshing losses, the cylinder speed should be 500 to 600 rpm (Sabir *et al*., 1990). With higher cylinder speed, the concave clearance should also be increased to reduce paddy breakage. A good concave clearance should be 20-25 mm and a good feed rate should be 12.1 to 17.4 t h^{-1} of vegetative material. Generally, the recommended cylinder tip velocity for peg tooth type combine harvester for paddy harvesting should be 12-16 m s^{-1} (Bawatharani *et al*., 2014), which may be achieved at 500-600 rpm of the threshing cylinder, but the owners of combine harvesters operate their machines beyond this tip velocity.

Harvesting losses: Harvesting losses include shattering and threshing losses. Manual harvesting losses were greater, which could be due to more crop handling processes, such as, cutting, bundling, transporting, stacking and threshing. Shattering losses in manual harvesting were up to 13% (Table 2). Conventional combine harvesters gave 5-12% shattering losses and 3-7% threshing losses, whereas, head-feeding combine harvesters gave 1.7-3.5% shattering losses and 0.5-1.5% threshing losses (Table 2). For semi-lodged crops, shattering and threshing losses were more (up to 19%) for conventional combine-harvested paddy. Standing crop gave less harvesting losses (up to 8%) and more head rice recovery (up to 60.2%) as compared with semi-lodged crop (average recovery of 47.6%), which is confirmed by the findings of Salassi *et al*. (2013). More ripened crop gave more shattering losses (up to 12%), due to impact force of reel and its shaking effect, which supports the findings of Khan and Salim (2005). The lodged crops gave harvesting losses up to 24%, when harvested manually. Threshing losses were due to harvesting of moist crop and improper rice kits installed on conventional combine harvesters.

Effect of crop standing on head rice recovery: Standing crop gave the highest head rice recovery for all harvesting methods. For instance, the highest head rice recovery was 63.8% for head-feeding combine harvesters and 60.6% for conventional combine harvesters in case of standing crop. For semi-lodged crops, the head rice recovery was lower for all harvesting methods. These results were consistent with those of Salassi *et al*. (2013).

Effect of crop health on head rice recovery: Healthy crops gave better head rice recovery for manual and combine-harvested paddy (Table 3). Weak crop gave more grain breakage during combine harvesting and yielded low head rice recovery during milling. For head-feeding combine harvesters, the average head rice recovery was 62.38% for healthy crops, 58.03% for medium crops and 52.27% for weak crops. Similarly, for conventional combine harvesters, the average head rice recovery was 58.23% for healthy crops, 54.46% for medium crops and 48.95% for weak crops. Means of head rice recovery for healthy, medium and weak crops were significantly different at 5% probability level for both combine harvesters (Table 3).

Results revealed that poor crop health is a significant factor towards a lower head rice recovery for combine-harvested paddy. The reason could be that the healthy grain was able to sustain more impact forces exerted by the threshing cylinder of combine harvester or impact forces of manual threshing as compared to weak grains. These results have been found consistent with those of Malik *et al*. (1981); Ali *et al*. (1990); Khan and Salim (2005); Hossain *et al*. (2009) and Roy *et al*. (2011), who reported that the rice yield was affected by crop health, variety trait, agronomic practices and harvesting time and method. However, they did not categorically determine the influence of combine harvesting methods on head rice recovery.

Table 1: Main specifications of combine harvesters used in this study.

Parameters	Conventional combine harvesters				Head-feeding combine harvesters			
	Type-1	**Type-2**	**Type-3**	**Type-4**	**Type-5**	**Type-6**	**Type-7**	**Type-8**
Make	NH	NH	NH	NH	Kubota	Kubota	Laverda	Daedong
Model	8040-50	8060	8070	8080	AR-40	R-9101G	M-82	DSM55
Drive type	Wheel	Wheel	Wheel	Wheel	Crawler	Crawler	Crawler	Crawler
Cutting width (m)	3.0-3.8	3.0-4.6	3.0-4.6	3.0-4.6	1.44	1.44	1.44	1.44
Engine power (hp)	90~95	110	130	150	50-60	50-60	50	50
Operating speed (km h^{-1})	2.0-3.5	2.5-3.5	3.0-3.5	2.5-3.5	2.0-3.0	2.2-3.0	2.1-3.0	2.0-3.2
Field capacity (ha h^{-1})	1.20-1.35	1.20-1.35	1.20-1.35	1.20-1.35	0.28-0.40	0.28-0.40	0.28-0.40	0.28-0.40

Note: NH = New Holland (brand name).

Table 2: Shattering and threshing losses for three paddy harvesting methods.

Harvesting method	Shattering losses	Threshing losses
Conventional combine harvesters	5 – 12 %	3 – 7 %
Head-feeding combine harvesters	1.7 – 3.5 %	0.5 – 1.5 %
Manual cutting and threshing	9 – 13 %	2 – 5 %

Table 3: Head rice recovery for different harvesting methods and types of crop.

Processing method	Healthy				Medium				Weak			
	Husk (%)	Bran (%)	Broken rice (%)	Head rice (%)	Husk (%)	Bran (%)	Broken rice (%)	Head rice (%)	Husk (%)	Bran (%)	Broken rice (%)	Head rice (%)
Head-feeding combine harvesters												
Laboratory	18.51 ±1.23	10.42 ±0.87	8.66 ±0.85	62.38^{a} ±0.57	19.45 ±0.35	10.98 ±1.19	11.51 ±1.71	58.03^{k} ±0.69	20.42 ±1.03	11.96 ±1.77	15.31 ±0.96	52.27^{x} ±1.24
Sheller	19.44 ±1.52	12.10 ±0.34	18.46 ±1.45	49.98 ±1.04	19.39 ±0.19	13.27 ±0.25	21.66 ±0.47	45.64 ±0.38	19.81 ±0.35	14.33 ±0.61	25.95 ±1.01	39.89 ±0.93
Conventional combine harvesters												
Laboratory	18.84 ±0.60	10.83 ±0.69	12.08 ±3.52	58.23^{b} ±2.49	19.50 ±0.24	12.19 ±0.88	13.81 ±2.16	54.46^{l} ±2.03	20.86 ±0.47	14.95 ±1.02	15.20 ±2.09	48.95^{y} ±2.33
Sheller	18.70 ±0.33	12.49 ±0.48	22.33 ±0.38	46.44 ±0.53	19.21 ±0.18	13.47 ±0.65	24.00 ±0.74	43.29 ±0.70	20.11 ±0.52	14.71 ±0.50	28.95 ±0.73	36.19 ±0.55
Manual harvesting and threshing												
Laboratory	19.58 ±0.71	10.33 ±0.78	5.86 ±1.14	64.24^{c} ±0.37	19.68 ±0.27	11.43 ±0.94	7.59 ±1.13	61.27^{m} ±0.53	20.23 ±0.90	14.18 ±0.96	10.61 ±0.96	54.81^{z} ±1.02

Note: The superscripts with different letters indicate that the means are significantly different at 5 % probability level.

Effect of moisture content on head rice recovery: At the time of harvest, crop moisture content ranged from 20 to 28%. Crop moisture content between 23 to 26% gave better head rice recovery for combine-harvested Super Basmati variety. Both conventional and head-feeding combine harvesters behaved alike at higher or lower moisture contents. The graph of head rice recovery at different moisture contents has been presented in Fig.3. The optimal harvesting moisture content was 23% (wb), which gave 58.5% average head rice recovery in local environmental conditions. Therefore, harvesting moisture content was identified as an important factor causing low head rice recovery for combine-harvested paddy. Geng *et al*. (1984) reported that the maximum head rice yield was obtained when paddy was harvested at moisture content between 20 to 27%. Furthermore, harvesting below 20% moisture content in Texas increased the percentage of broken kernels for short- and medium-grain paddy during milling process. Similarly, harvesting at moisture content above 30% reduced head rice recovery due to more immature kernels or less broken kernels during milling. Siebenmorgen *et al*. (2006) reported that the optimal harvesting moisture content for long grain paddy ranged 19 to 22% and for medium grain paddy ranged 22-24%, if harvested at proper time. Similarly, the optimal milling moisture content is also very crucial to get a better head rice recovery. In this study, the milling moisture content was controlled between 11 to 13% as it was generally reported that the milling moisture content should be in the range of 10-15% for most paddy varieties (Malik *et al*., 1980).

Effect of harvesting method on head rice recovery: Head-feeding combine harvesters gave better results for all types of crops (healthy, medium and weak) than the conventional combine harvesters. The highest head rice recovery was obtained for manual harvesting and threshing method. The average head rice recovery from healthy, medium and weak crops was 57.56, 53.88 and 60.11%, for head-feeding combine harvesters, conventional combine harvesters and manual harvesting method, respectively (Table 3).

The results revealed that the harvesting method is very crucial for low head rice recovery. Head rice recovery was higher for head-feeding combine harvesters than the conventional combine harvesters, which is attributed to the fact that head-feeding combine harvesters are specifically designed for harvesting paddy crop, in which tooth peg drum gently beats the rice heads only, whereas, in case of conventional combine harvesters, rice heads along with crop stalks are beaten repeatedly and rigorously to separate rice from heads. Conventional wheat combine harvesters have been modified locally by installing rice kits for paddy harvesting. Local workshops do not possess any research and development facility for minimising the breakage of paddy kernels. These workshops also lack speciality and precision for fabrication of rice kits for wheat combine harvesters. For instance, very accurate spacing is required between spike teeth, profile and concave of threshing unit to prevent kernel breakage. Similarly, the clearance between a spike tooth and stationary shoe of concave should also be maintained precisely. Otherwise, this may produce fissured, cracked or husked kernels, if this clearance is too narrow or causes higher threshing losses, if this clearance is too large. The owners of the combine harvesters are only concerned with their incomes, who try to operate combine harvesters at higher forward and threshing cylinder speeds. They are not really concerned with the financial loss resulting from their machines to farmers and the country. Therefore, these rice kits need special attention to reduce breakage for harvesting Basmati rice. Otherwise, head-feeding combine harvesters are more suitable than the conventional combine harvesters for paddy harvesting. Moreover, head feeding combine harvesters are track type machines, which induce minimum soil compaction as compared with wheat combine harvesters, which are of wheel type. Conventional combine harvesters thresh paddy grains in repeated quick and severe blows. This introduces cracks in paddy grains, which break during milling operation. In this study, conventional and head-feeding combine harvesters gave 6.23% and 2.55% less head rice recovery than the manual harvesting method, respectively. This result is consistent with those of Ali *et al*. (1990), who reported up to 6% lower head rice recovery, using conventional combine harvesters as compared with manual harvesting and threshing method.

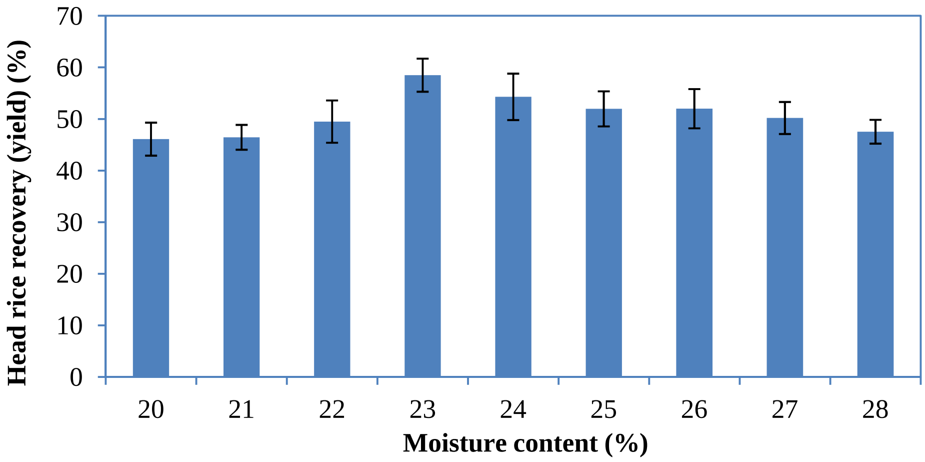

Fig. 3: Head rice recovery (yield) at different harvesting moisture contents.

Relation between head rice yield and broken rice: The relation between head rice recovery and broken rice is shown in Fig. 4. The high value of R^2 = 0.94 indicated best fitness of linear model. As the amount of broken rice increased, the head rice recovery decreased and vice versa. The proportion of husk and bran in all processing methods was about 20% and 10%, respectively (Table 3). The increase in amount of broken rice during milling could be attributed to the increased impact force of threshing cylinder, which leads to internal cracks in the kernels depending on crop variety, grain moisture content and feed rate (Srivastava *et al*., 1995; Mohtasebi *et al*., 2006). The strength for bearing impact force of cylinder is different for long-grain, medium-grain and short-grain paddy varieties. Hence, combine-harvested paddy receives a lower market price than the manually harvested paddy crop.

Effect of village level shellers on head rice recovery: Village level shellers are widely used for paddy milling in villages. A village sheller is of low capacity and yields low quality and low head rice recovery. The performance of these shellers was also lower than rice mills and laboratory equipment. For healthy crop, the maximum head rice recovery was 49.98, 46.44 and 51.74% for head-feeding combine harvesters, conventional combine harvesters and manual harvesting method, respectively (Table 3). Although the trend of recovery was similar to that of laboratory results, yet the maximum head rice recovery was less than 52%. Village level shellers have their own limitations, as these yield low head rice recovery and cause damage to paddy kernels during one step husking and polishing process, which is a big source of loss for local farmers and for the economy of the country.

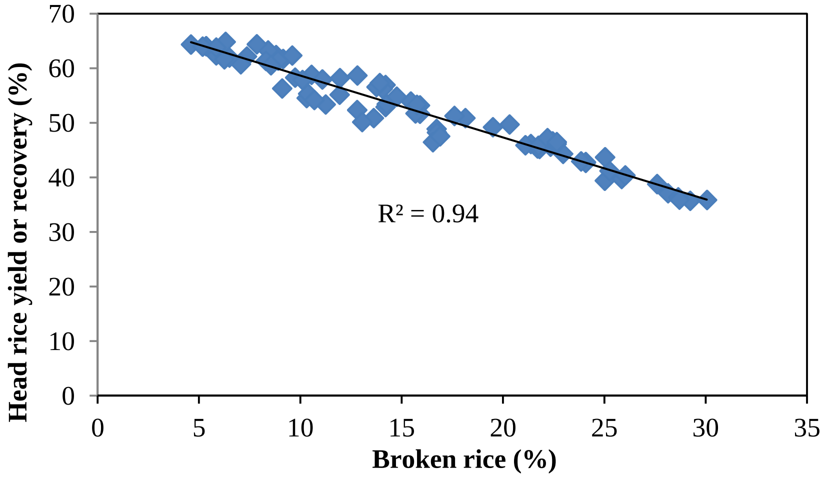

Fig. 4: Relation between head rice yield and broken rice.

CONCLUSION

Factors causing low head rice recovery in combine-harvested paddy were studied for both conventional and head-feeding combine harvesters. Conventional combine harvesters gave more shattering and threshing losses and lower head rice recovery. They induce impact threshing forces on paddy kernels, which result in higher percentage of broken rice during milling. Head-feeding combine harvesters gave better head rice recovery and lower shattering and threshing losses. Manual harvesting and threshing method gave the highest head rice recovery, but higher shattering and crop handling losses. Other factors that were responsible for low head rice recovery included crop stand, crop moisture content, machine forward speed, threshing cylinder speed and operator's skill. Operator's skill was perhaps the most critical factor to control broken rice during combine harvesting of paddy crop. Head-feeding combine harvesters produced lower broken rice than the conventional wheat combine harvesters and, therefore, are more viable option for paddy harvesting.

RECOMMENDATIONS

Keeping in view the findings of the study, the following recommendations are made for the policy makers to implement them to save losses to the national economy:

i) Head-feeding combine harvesters with higher field capacity (cutting width ranging from 3 to 4 m) may be introduced for paddy harvesting.
ii) Proper training of operators of combine harvesters should be mandatory.
iii) Standardised and improved design of rice kits should be introduced for installation on conventional combine harvesters for paddy harvesting.
iv) A legislation may be passed to forbid rental companies to harvest immature paddy crop.
v) Optimum ground and drum speed of combine harvesters should be used for paddy harvesting.
vi) Mechanical dryers should be used at trader level to minimise paddy losses due to aflatoxins.

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