Original Scientific paper
10.7251/AGRENG2001094A
UDC 631.554:633.18

RICE LOSSES CHARACTERISTICS IN VARIOUS HARVESTING METHODS

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ABSTRACT

Grain loss is inevitable during harvesting operations and attempts are made to identify and minimize that. In this study, field performance of five different harvesting methods were assessed which included three indirect harvesting methods of (i) manual cutting + threshing by a tractor driven thresher (T_1), (ii) rice reaper + threshing by a tractor driven thresher (T_2), (iii) rice reaper + threshing by universal combine harvester equipped with pickup type header (T_3), and two direct harvesting methods of (iv) head-feed rice combine (T_4), and (v) whole-crop rice combine (T_5). The results revealed that the maximum and minimum effective field capacity related to whole-crop combine (0.361 ha h^{-1}) and manual cutting (0.009 ha h^{-1}), respectively. Quantitative losses (grain and panicle shattering) in harvesting and threshing obtained to be 2.58% and 2.33% in average on indirect harvesting (T_1, T_2 and T_3) and direct harvesting (T_4 and T_5), respectively which were not significant statistically. The average qualitative losses (broken, husked and cracked grains) were 2.30% for indirect harvesting and 0.61% for direct harvesting that showed a decline of 63.3% compared to indirect harvesting. Total harvesting losses were 5.07% for T_3 (maximum) and 2.74% for T_4 (minimum). The harvesting method affected the percentage of broken rice after milling significantly. The average broken rice for T_1, T_2 and T_3 was 23.72, 23.28 and 24.56% respectively which were significantly higher than T_4 (21.05%) and T_5 (20.87%). Also, in the view of loss reduction, applying rice combine harvesters had priority respect to indirect harvesting methods.

Key words: *Rice harvesting, combine harvester, losses, milling.*

INTRODUCTION

Harvesting operations are known as crucial and influential processes on quantity, quality and production cost of rice. Manual harvesting of rice is such a troublesome, time-consuming and costly operation that it needs about 100-150 man-hour per hectare labor. On the other hand, labor shortage and wage rise over work peak period will cause delay in operations and increase of grain and panicle shattering so that farmers encounter severe detriments. In addition, because of seasonal rainfall in northern parts of Iran at harvest time, rice stalks tend to lodge.

Hence, mechanized harvesting operations gets into trouble and the number of labors required for manual harvesting gets up to double. Therefore, it is required to conduct technical and economic investigations for determining appropriate type on the viewpoint of existing conditions across the region.

Investigations by Ali *et al.* (1990), Siebenmorgen *et al.* (1998), Surek and Beser (1998), and Hossain *et al*. (2009) stated that harvest time had significant effect on head rice yield (HRY) so that it was required harvesting on optimum rough rice moisture content to obtain uttermost HRY. If rough rice moisture content becomes lower than critical level, broken rice percentage will raise significantly.

Other researchers examined field performance of different combine harvesters. Kalsirislip and Singh (1999) reported that in a combine equipped with a 3m width head stripper, field capacity and field efficiency were 0.66 ha $h^{-1}$and 74% for standing crop and 0.3 ha h^{-1} and 72% for lodged crop, respectively. Bora and Hansen (2007) examined field performance of a portable reaper for rice harvesting and compared it with manual harvesting. They reported that grain loss was 2.3% and 1% for reaper and manual harvesting, respectively.

Loveimi *et al*. (2008) investigated losses of two rice combine harvesters equipped with spike-tooth and rasp-bar threshing units. In direct harvesting, the average crop loss was 1.73 and 3.68% for spike-tooth and rasp-bar combines, respectively. In indirect harvesting, it was reported 3.45%. Alizadeh (2003) appraised field performance of two types of rice reapers namely self-propelled and power tiller driven against manual harvesting. He pointed out that harvesting loss was the lowest in manual method while it was the highest with power tiller driven reaper. Therefore, this study aimed to investigate technical and field aspects of utilizing rice combine harvesters and comparing them with indirect harvesting on the view of quantitative and qualitative grain losses.

MATERIALS AND METHODS

This study was conducted at experimental station of Rice Research Institute of Iran, Rasht, Iran in the cropping season of 2016-2017 where a high yielding cultivar (Fadjr) had been cultivated. Five harvest methods examined as follows:

i. Manual harvesting (cutting with sickle) + tractor driven thresher (T_1),
ii. Rice reaper + tractor driven thresher (T_2),
iii. Rice reaper + threshing by a universal combine equipped with pick-up header (T_3),
iv. Head-feed rice combine harvester (T_4),
v. Whole-crop rice combine harvester (T_5)

Treatments T_1, T_2 and T_3 are considered as indirect harvesting but treatments T_4 and T_5 are known as direct harvesting.

Figure 1 shows machines used in the experiments. In the indirect harvesting (T_1, T_2 and T_3), cut paddy stalks were left across the field around 24 hours to reduce moisture content and then gathered and threshed by a tractor driven thresher. Before operations, crop conditions were measured in terms of plant height, number of hills per unit area, grain moisture content and grain separating force from panicle (Table 1). Rough rice moisture content was determined by a grain moisture meter (GMK 303 RS, Korea) at harvest time. To determine soil penetration resistance at harvest time, a cone penetrometer (Eijelkamp, UK) was used for measuring soil cone index up to 25 cm deep underneath soil surface whose standard cone had a base area of 5 cm^2 and diameter of 25.23 mm. Grain separating force from the panicle was measured as an indication of grain shattering level as described by Alizadeh and Allameh (2011).

Figure 1 Machinery used in harvesting tests

Table 1. Agronomic features of used cultivar and field conditions at harvest

Treatment	Plant height (cm)	No. of hills per m^2	No. of plant per hill	Grain yield (kg m^{-2})	Grain moisture content (wb)	Cutting height (cm)	Grain detaching force (N)	Soil cone index (kPa)
T_1	112.5^a	17.5^a	20.3^a	0.70^a	18.6^a	43.1^a	0.81^a	972^b
T_2	112.8^a	18.2^a	18.6^a	0.65^a	18.2^a	16.8^c	0.84^a	1116^a
T_3	117.4^a	19.0^a	18.8^a	0.73^a	19.4^a	14.2^c	0.70^a	812^b
T_4	114.2^a	18.0^a	18.0^a	0.61^a	20.1^a	37.8^a	0.85^a	900^b
T_5	113.0^a	19.7^a	19.2^a	0.58^a	21.6^a	34.20^b	0.74^a	944^b

In each treatment, performance parameters of harvesting machines were measured which included travel speed, working width, lost time and total required time. To determine travel speed within operation, time required to traverse 30 m over harvesting was recorded by a digital timer. This was repeated four times in each plot. Theoretical field capacity (C_t), effective field capacity (C_e), work capacity (W_c), and field efficiency (F_e) of harvesting machines obtained from the following formulas (Hunt, 1995; Konaka, 2005):

$$C_t = \frac{W \times S}{10} \qquad (1)$$

$$C_e = \frac{S \times W_e}{10} \qquad (2)$$

$$W_c = \frac{1}{C_e} \quad (3)$$

$$F_e = \frac{T_e}{T_t} \times 100 \quad (4)$$

Where, C_t: theoretical field capacity, ha h^{-1}, C_e: effective field capacity, ha h^{-1}, W: working width, m, S: travel speed, km h^{-1}, T_t: total time, h, T_e: useful time, h, W_c: work capacity, h ha^{-1}, F_e: field efficiency, %.

To determine quantitative loss before and after harvesting on manual cutting and reaper harvester, a 1m×1m wooden frame was thrown out randomly over four spots in each plot. The grains inside the frame were gathered and weighted. In combine harvesters, losses are observed at two main units i.e. cutting and threshing units (Sangwijit and Chinsuwan, 2010). Therefore, the wooden frame was thrown out back and forth sides of the combine and all grains and panicles inside it gathered and weighted (Roy *et al.,* 2001). Then, the weight percentage of harvesting loss computed by the following formula (Pradham *et al.,* 1998):

$$HL = \frac{W_{gt} - W_{go}}{Y} \times 100 \quad (5)$$

Where, HL: harvest loss, %, W_{gt}: total harvest loss, g m^{-2}, W_{go}: pre-harvest loss, g m^{-2}, Y: grain yield, g m^{-2}.

For determining loss on the threshing stage, a wide plastic sheet was spread over a flat surface and the thresher settled on it. In the experiments, the threshing chamber was fed uniformly and afterward all the grains and the panicles on the plastic sheet gathered and weighted. The weight percentage of the loss derived as a ratio of the weight of the grains thrown out of different parts of the thresher to total grain weight (sum of the grains weight collected from the main outlet and the weight of the grains thrown out).

To determine the percentage of the broken and husked grains, four samples of 100 g rough rice was taken from the outlet of the thresher and the rice combine harvester and then the broken and husked grains separated manually and weighted (Srivastava *et al.*, 1998). To compute cracked grains percentage in each replication, 50 intact kernels of rough rice were randomly selected and their husks were carefully removed by hand. Then, brown rice kernels were placed on the crack tester (Mahsa, 50, Iran). The number of cracked ones counted and weighted.

In order to study the effect of harvest method on milling properties i.e. milling recovery, broken and head rice yield, from each treatment four samples of 150 g rough rice were randomly selected from the outlets of the thresher and combines. All impurities in the samples were removed by hand. Afterwards, samples were placed in an electrical oven with 43°C (Alizadeh *et al.*, 2006) to be dried up to 9% (w.b.). Dried rough rice samples were then husked by a laboratory rubber roll husker (THU35B, Satake Corp., Japan). Next, the outlet of the husker (brown rice) whitened by a laboratory friction-type rice whitener (Baldor, McGill Miller No. 2, USA). A rotary indented grader (TRG058 Model, Satake test Rice Grader, Japan) was used to separate broken kernels from head ones. Milling recovery and head rice yield were calculated as described by Allameh and Alizadeh (2013). Data analysis was done using SAS 9 (2004, SAS Institute, US) as randomized complete block design (RCBD) laid out in data analysis of variance with five treatments and four replications. Means comparison was conducted by Duncan's multiple range tests.

RESULTS AND DISCUSSION

Field performances of harvesting machines have been shown in Table 2. Among the harvest methods, universal combine harvester equipped with pick-up header has the least travel speed (1.63 km h^{-1}). In this system, combine harvester moves along the field and performs threshing of what has been cut in advance. Also, the results indicated that the highest travel speed belonged to self-propelled reaper in the experiments which it was due to low weight of machine and higher maneuverability.

Table 2. Field performance of machinery used in tests

Treatment	Travel speed (km h^{-1})	Working width (m)	Total work time (min)	Waste time (min)	Useful time (min)	TFC (ha h^{-1})	EFC (ha h^{-1})	Wc (h ha^{-1})	FE (%)
T1	-	-	665.70	31.00	636.70	-	0.009	111.10	-
T2	2.54	1.2	25.02	5.28	19.74	0.304	0.240	4.17	78.90
T3	1.63	2.40	19.80	4.45	15.35	0.391	0.303	3.30	77.54
T4	2.37	1.40	24.60	5.70	18.90	0.331	0.254	3.93	76.83
T5	2.08	2.38	16.62	4.50	12.14	0.495	0.361	2.77	73.09

Theoretical and effective field capacities of the whole-crop combine were 0.495 and 0.361 ha h^{-1}, respectively which were the highest compared to the other treatments. According to (1), theoretical field capacity depends on working width and machine travel speed. Also, in accordance with (2), effective field capacity is a product of theoretical field capacity by field efficiency. Although, its working width was more than whole-crop combine but because of lower travel speed during harvesting, field capacity of the cereal crop combines equipped with pick-up header was less than whole-crop rice combines.

Working capacity (time required to harvest one hectare) was the highest in manual harvesting with the mean of 111.10 h ha^{-1} while in the whole-crop combine it was the least with the mean of 2.77 h ha^{-1}. The maximum working capacity belonged to a treatment which had the minimum effective field capacity because, based on (3), working capacity was obtained by inverting effective field capacity. Field efficiency varied from 73.09% on the whole crop combine to 78.90% on the self-propelled reaper. This feature depends on wasted time, type and agronomic characteristics of a variety, plot size and operator's skill. Kalsirislip and Singh (1999) reported that for a combine equipped with a 3 m working width head stripper, field capacity and field efficiency were 0.66 ha h^{-1} and 74% for standing crop and 0.3 ha h^{-1} and 72% for lodged crop, respectively. Roy *et al.* (2001) expressed that field capacity and field efficiency of a whole-crop rice combine harvester were 1.05 ha h^{-1} and 72%, respectively for a common rice variety in Malaysia. Veerangouda *et al.* (2010) reported that field capacity for a tractor operated combine harvester was varied from 2.88 to 3.60 ha h^{-1}.

The average quantitative losses were 2.58 and 2.33% for indirect harvesting (treatments T_1, T_2, and T_3) and direct harvesting (treatments T_4 and T_5), respectively (Table 3). In indirect harvesting, loss on cutting and gathering stages was higher than the threshing stage. Among the harvest methods, the maximum and minimum quantitative losses were related to T_3 (2.66%) and T_4 (2.27%), respectively.

Table 3. Means comparison of tested parameters

Treatment	Quantitative losses		Qualitative losses				Total losses	Impurity %
	Reaper and gathering	Threshing	Broken paddy	Husked paddy	Broken and husked	Cracked grains		
T_1	1.60^{b}	0.98	0.53^{a}	0.21^{a}	0.11^{b}	1.20^{a}	4.63^{a}	2.63^{a}
T_2	1.48^{b}	1.04	0.48^{ab}	0.23^{a}	0.10^{b}	1.63^{a}	4.96^{a}	2.52^{a}
T_3	1.54^{b}	1.12	0.61^{a}	0.25^{a}	0.27^{a}	1.28^{a}	5.07^{a}	2.78^{a}
T_4	2.27^{a}	-	0.13^{a}	0.07^{b}	0.04^{b}	0.23^{b}	2.74^{b}	2.26^{a}
T_5	2.40^{a}	-	0.24^{b}	0.16^{ab}	0.08^{b}	0.27^{b}	3.15^{b}	2.34^{a}

In each column, figures with common letter have no significant difference at 5% level.
In combine harvesting (T_4 and T_5), cutting and threshing losses are considered in the lump.

In the indirect harvesting, qualitative loss obtained 2.30% on average, but it was 0.61% in direct harvesting which showed a decline of 73.5%. Amidst the indirect harvest methods, the highest and lowest qualitative loss found to be 2.44 and 2.05% for treatments T_2 and T_1, respectively. Qualitative loss was determined 0.47 and 0.75% for treatments T_4 and T_5, respectively. Total harvest losses (quantitative and qualitative) were the highest for treatment T_3 (5.07%) while the lowest (2.74%) belonged to treatment T_4. In general, total harvest losses in indirect method averaged out 4.88% but it was 2.94% in direct method which decreased 39.75%.

The proportion of harvest losses in each stage of the experiment is shown in Figure 2. As it shows, quantitative and qualitative losses are 79.5 and 20.5% in direct harvesting by rice combines but they are 53.30 and 46.70% in indirect harvesting, respectively. The results indicated that the harvest loss in the direct method occurred mainly on the cutting stage. Qualitative loss constituted a considerable proportion of total harvest losses in the indirect harvesting. Among the experiment stages for all harvest methods, reaping had the highest proportion in the loss whereas the broken and husked grains had the lowest proportion in it. Also, the cracked grains had the highest proportion amid the qualitative losses. This was explicitly observed in the indirect harvesting, as it was mentioned earlier, where environmental tensions applied on the grains during cutting and threshing operations.

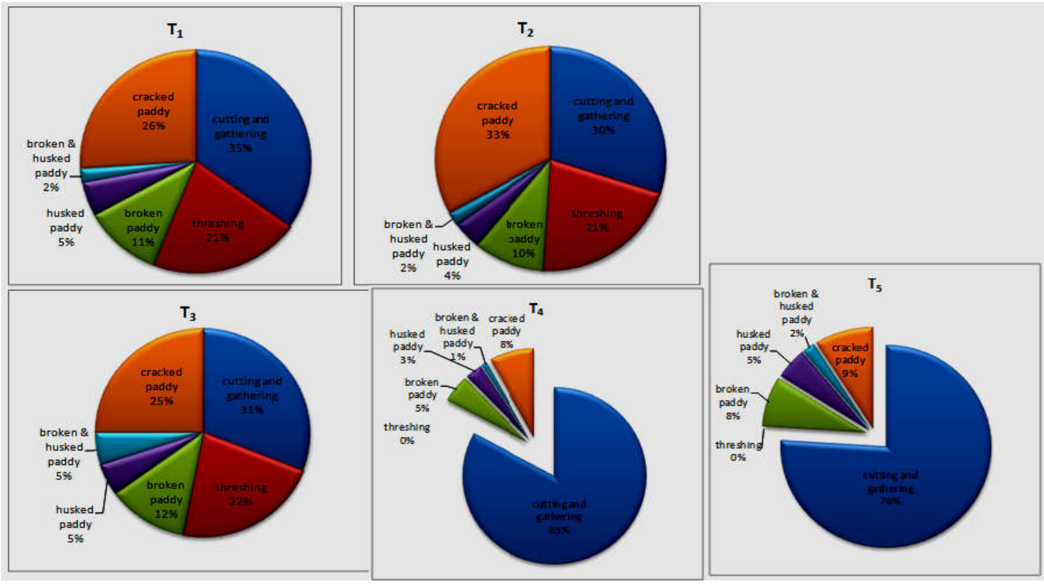

Figure 2. Contribution of different stages in harvest losses

In their research, Loveimi *et al.* (2008) reported that rice harvest losses in the indirect method were 3.77 and 1.67% by a combine equipped with rasp-bar and spike-tooth type threshing drum and they were 3.6 and 1.8% in direct method, respectively. Harvest loss of a rice combine harvester was 1.68% for a common variety in Malaysia (Roy *et al.* 2001). Fouad *et al.* (1990) in their investigations in Egypt reported that harvest losses were 178-380 kg ha^{-1} for a common variety harvested by rice combines.

In general, loss could be attributed to harvest and threshing method, harvest time, type of variety and its physical properties, crop condition in terms of maturity, lodging and soil condition. In indirect harvesting, cut paddy is laid out on stubbles from 24 to 48 hours depending on the weather conditions. Then, they are collected and threshed. Therefore, crop moisture reduction would lead to not only a rise in grain shattering during gathering and packing but also paddy would be exposed to environmental tensions that bring about crop qualitative loss in consequence.

Table 4 shows the comparison of rough rice milling properties obtained by different harvest methods. The average milling recovery was 67.00% in indirect harvesting treatments and 67.72% in direct ones which indicated a significant difference ($p<0.05$). Also, the broken and head rice yield was 23.85 and 76.15% in indirect harvesting and 20.96 and 79.04% in direct one, respectively.

Table 4. Milling losses in different harvest methods

Treatment	Milling recovery (%)	Broken rice* (%)	Head rice* (%)
T_1	66.58^{b}	23.72^{a}	76.30^{a}
T_2	67.07^{b}	23.28^{ab}	76.73^{a}
T_3	67.32^{ab}	24.56^{a}	75.45^{a}
T_4	67.24^{ab}	21.05^{b}	78.95^{a}
T_5	68.20^{a}	20.87^{b}	79.13^{a}

* Broken and head rice are derived from total milled rice.
In each column, figures having the same letter have no significant difference.

As the results have shown, the broken rice in the indirect harvesting was significantly higher than the direct one. This, on one side, could be attributed to the mechanical stresses applied on the grains during harvesting and threshing and on the other side environmental tensions due to reabsorption of dried grains across the field and their crack formation which results in rise of the broken rice and fall of head rice yield within milling process. This has been approved by Siebenmorgen *et al.* (1998); Nguyen and Kunze (1984); Banaszek and Siebenmorgen (1990).

CONCLUSION

The maximum and minimum effective field capacity averaged to 0.361 and 0.009 ha h^{-1} for treatments T_5 and T_1, respectively. Time requirement was 111.10 h ha^{-1} for manual harvesting (T_1) but it was 3.54 h ha^{-1} for mechanized treatments (T_2, T_3, T_4 and T_5) on average which saved 96.80% compared to manual method. Quantitative and qualitative losses constituted 53.30 and 46.70% of total harvest loss in indirect harvesting on average, while they were 79.50 and 20.50% in the direct harvesting on average, respectively. Total harvest loss was 4.88% in the indirect harvesting whereas it was 2.95% in the direct method which declined 39.75%.

ACKNOWLEDGEMENT

This article reveals some findings of a research project approved and supported by Rice Research Institute of Iran under registration No. of 4-04-04-88028. The authors would like to express their gratitude.

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