Optimization of Conventional Combine Harvester to Reduce Combine Losses for Basmati Rice (*Oryza Sativa*)

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Abstract

A study was conducted at PAU Regional Research Station, Gurdaspur (Punjab) to investigate the design and operational parameters of threshing mechanism of conventional combine harvester for basmati crop. This study was aimed to investigate the suitable changes required in the self-propelled conventional combine harvester for harvesting the basmati crop with minimum grain losses. Field evaluation of experiment was carried out to assess the influence of independent design variable *i.e.*, arrangement of spikes (AS) and independent operational parameters such as concave clearance (CC) and cylinder speed (CS). The study was aimed to enumerate various combining losses *viz.*, extent of visible and invisible grain damage and threshing efficiency at different AS, CC and CS levels. The first year data recorded during 2017 were processed for the optimization during 2018. The results of the present study revealed that during 2017, maximum visible and invisible losses was 5.49% ± 0.33% and 28.07% ± 3.21%, respectively whereas after modification, these losses remained only 4.00% ± 0.80% and 24.07% ± 2.86%, respectively. The threshing efficiency remained above 99.31% ± 0.47%, for both years. Thus, optimization of combine harvester was able to save the visible grain damage by 60% to 83% and invisible grain damage by 6% to 16%, respectively during 2018 than the year 2017.

Keywords

Conventional Combine Harvester, Basmati Rice, Visible and Invisible Grain Damage

1. Introduction

Paddy is an important staple food crop of the world including India. Basmati rice is popular among the farming communities for domestic consumption and good export commodity. Basmati is traditionally grown in India [1] and Pakistan [2]. During 2018-19, India shared for 95% of the international trade in basmati rice, while remaining 5% was contributed by Pakistan. India accounts for over 70% of the world's basmati rice production [3] from GI tag holding basmati growing Indian states such as Punjab, Haryana, Himachal Pradesh, Delhi, Uttarakhand, Western Uttar Pradesh, and Jammu and Kashmir [4]. The basmati trade has been tremendously increased from 0.771 million metric tonnes during 2003 to 4.41 million metric tonnes during 2018-19 [5]. Saudi Arabia, Iran and UAE are the three biggest destinations for India's Basmati rice exports and these three countries accounted for more than half of India's total Basmati exports [6]. In Indian Punjab state, total basmati area during 2017 and 2018 was 561.45 and 549.20 thousand ha area.

Threshing *i.e.*, the removal of grains from the plants is one of the most important process in crop production system [7] [8]. Generally, harvesting and threshing of paddy is performed either manually or by using the power threshers but nowadays, harvesting with combine is common in the country especially in Punjab. Because, the manual rice harvesting requires lot of the skilled human labour and time. In this context, [9] reported that total labour requirement for manual transplanting, harvesting and threshing of paddy is approximately equivalent to the 15.3%, 22.1% and 10.9% of the total rice production. Sometimes during the peak periods of harvesting and threshing, non-availability of labours often cause delay the operation of harvesting which successively decrease the yield of next crop *i.e.*, wheat due to delay in sowing [10]. Additionally, manual harvesting and threshing operation is quite costly because, it is mostly done by hired labour. The threshing cost and family labour jointly account for the worth equivalent to Rs. 4704 per hectare [11]. In the era of fast industrialization, it is difficult to find sufficient manpower therefore, commercial machines for paddy harvesting and threshing are needed to be designed, evaluated and promoted for basmati rice crop. On the other hand, the combine harvester can harvest and thresh the crop in a single operation. Thus, it not only helps in timely harvesting and threshing of the crop but, also reduces the manpower and cultivation cost besides, lowering the risks from the weather hazards. Though, the available harvesting cum threshing combines is not readily suitable for basmati varieties because of relatively delicate nature [12].

In India, most of the combine harvesters generally employ rasp-bar or spike-tooth type tangential threshing drums and straw walker [13]. Traditional combines have very less cylinder to CC (*i.e.*, around 25 mm at inlet and 10 mm at concave outlet). In spike tooth type threshing cylinders, the CC may be reduced up to 7 mm [14] which in turns resulted into the aggressive threshing action. Consequently, this aggressive threshing action caused high visible and invisible grain damage, particularly in paddy crop. The grain damage is associated with reduced recovery of whole grain during milling operation hence, grain quality deterioration was major concern with such types of harvesting mechanisms. Ultimately, the damage rate of grain threshing negatively affects the market value and storage capacity [15]-[20]. In axial flow combines, crop progresses through the threshing mechanism parallel to the axis of the rotor whereas in conventional threshing cylinder, the crop advances through the threshing mechanism perpendicular to the axis of the rotor. The rotor threshes the grain by a combination of rubbing, impact and centrifugal actions repeatedly. There are more than three drum rotations in both the cases, the difference is only in the degrees of rotation *i.e.*, 1080˚ in axial threshing system and 120˚ - 150˚ in tangential cylinder. The repeated passes in the axial based threshing system provide more retention time with gentle threshing action. Since, the retention time as well as cylinder to CC was more in axial threshing drum in comparison to the tangential threshing drums thus, the threshing is less aggressive in first case. The advantage of axial flow combines over conventional combines is in terms of separation loss confirmed by [21] however; the cost of axial attachment may deter the combine operators. Likewise, operation in controlled conditions has resulted a non-significant difference in grain loss among the commercially available machines. Moreover, there are machine constraints in case of axial flow combines, as they are not available for custom hiring.

Therefore, looking to the various sources of damages and quality losses of grains in combine harvesters, evaluation and standardization of the combines for harvesting of the precious Basmati crop was felt to be urgently undertaken. Hence, present investigation was carried out with an objective of optimization of the conventional combine harvester for lowering the grain damage of Basmati rice in Indian Punjab conditions.

2. Materials and Methods

2.1. Experimental Site

The field testing of the present investigation was carried out at experimental farm of Punjab Agricultural University, Regional Research Station, Gurdaspur, Punjab (Latitude 32˚04N'; Longitude 75˚40'E; Altitude 241 m amsl) during 2017. However, the optimization in the tested combine machine was carried out during the subsequent year 2018.

2.2. Climatic Conditions

The experimental site falls under northern part of the Punjab state (Agro climatic zone-II) popular as undulating plain region of Punjab. The altitude of the zone varies between 213 and 305 msl. The average maximum temperature 40˚C to 41˚C reach during the first fortnight of June whereas, the minimum temperatures 6˚C to 7˚C are recorded during January. Frost is experienced often during December-January. The annual total rainfall varies between 800 and 900 mm.

2.3. Experimental Design and Treatments

Field evaluation of the experimental setup was carried out using randomized block design. The three treatments for the harvesting and threshing of the basmati rice were AS, CS and CC and each treatment had three levels forming 27 (3 × 3 × 3) treatment combinations. Each treatment was replicated thrice to make total number of trial runs equal to 81 (27 × 3). The sequence of trial runs/ experiments was selected following the randomization. AS in the form of helix was major operation. The CS at different helical AS and CC was also studied. In addition, the effects of CC over different helical pattern of spikes and at different CS were observed. From each treatment the visible loss, invisible loss and threshing efficiency were separately computed. Different combination of the independent factors were tried to find out the best combination at which less loss and more profitability appeared.

2.4. Crop and Cultivar

The basmati rice cultivar PUSA Basmati—1121 being about 120 cm tall possesses extra long slender grains with good cooking quality [22]. Among the aromatic rice varieties recommended for Punjab, PUSA Basmati—1121 has longest cooked rice length. It is photoperiod insensitive and matures in about 137 days after seeding. The average yields of this cultivar is 34.3 q/ha (http://www.pau.edu/content/pf/pp_kharif.pdf).

2.5. Collection of Samples

The three samples of grains approximately 250 g each were taken for the whole experimental setup to determine the visible losses at variable cylinder speeds for different AS and CC. Thus for each experiment, from 50 g sample the broken grains were separated and weighed for visible grain damage assessment. The whole procedure was repeated by varying the peripheral speed. For the measurement of the invisible grain damage, fifty sound grains were randomly selected from cleaned basmati rice samples. These grains were shelled with hand before detecting the cracks. Thereafter, these sampled grains were placed on the slits, provided in the paper that was fixed on the glass surface of the purity board. The internal cracks in grains were determined with the help of an illuminated purity board.

2.6. Evaluation Procedure

Preliminary field evaluation of the present experimental prototype was carried out at Regional Research Station, Gurdaspur (Punjab). The conventional combine harvester was operated for the harvesting of PUSA Basmati-1121. Preliminary field testing of prototype was operated at a forward speed of 1.5 km/h. Test setup was able to cover 20 m in one minute. A field more than 100 m long and 40 m wide was selected for evaluation of test setup. It was assumed that 10 meter run was sufficient for turning of combine harvester.

2.7. Conventional Combine Harvester

The self-propelled conventional combine harvester was used to study the effect of selected design and operational parameters of threshing mechanism for basmati crop. Brief specifications of the machine used for present investigation are given in Table 1.

2.8. Independent Variables

In present study, the effect of arrangement of spikes, CC and CS of combine on grain damage were studied. The levels of various independent variables are given in Table 2. Spikes were arranged on the threshing drum in the form of helical arrangement. The varying CS with changing the pulleys was measured by tachometer in rpm. Throughout the experiment, the forward speed of 1.5 km per hour was maintained.

2.9. Dependent Variables

Performance of the combine was assessed in terms of the visible grain damage, the invisible grain damage and the threshing efficiency. The broken grains were separated from this sample and weighed. Percentage visible grain damage was calculated using following formula (1):

Table 1. Brief specifications of conventional combine harvester.

S. No.	Particular	Specification
1	Chassis	51”
2	Front wheel Rear wheel	18-04-30 9-00-16
3	Number of straw walkers Number of steps	5 5
4	Weight	8500 kg (approximately)
5	**Cutting capacity for** Wheat Paddy	 3 - 4 acre per hour 2 - 3 acre per hour
6	Overall dimensions (transport)	Length: 12,060 mm, Width: 3200 mm Height: 3700 mm
7	Overall dimensions (working)	Length: 8450 mm, Width: 4700 mm Height: 3700 mm
8	Effective cutting width	4300 mm

Table 2. Independent variables/parameters during 2017 and 2018.

Levels: Three (3)	Year 2017	Year 2018
AS: Arrangement of spikes (No. of spikes)	1) AS1: 44, 2) AS2: 68, 3) AS3: 136	1) AS1: 36, 2) AS2: 44, 3) AS3: 52
CS: Cylinder speed (rpm)	1) CS1: 560, 2) CS2: 640, 3) CS3: 720	1) CS1: 480, 2) CS2: 560, 3) CS3: 640
CC: Concave clearance (mm)	1) CC1: 13 - 9, 2) CC2: 15 - 11, 3) CC3: 17 - 13	1) CC1: 15 - 11, 2) CC2: 17 - 13, 3) CC3: 19 - 15

$$\textbf{Visible grain damage}(\%) = \frac{\text{Weight of broken grains}}{\text{Weight of sample}} \times 100 \quad (1)$$

Likewise, for invisible grain damage assessment, internal cracks in grains were determined using an illuminated purity board. With the help of a magnifying glass, the cracks in the grains were determined. The percentage of invisible grain damage was calculated using aforementioned formula (2) adopted from [23].

$$\textbf{Invisible grain damage}(\%) = \frac{\text{Number of cracked grains}}{\text{Total number of grains inspected}} \times 100 \quad (2)$$

The unthreshed grains in ear heads determine the effectiveness of threshing. Ratio of weight of unthreshed grains in ear heads to threshed grains collected from all outlets was referred as the threshing efficiency, generally expressed in percent. Cylinder over throw *i.e.* straw ejected out from tangential cylinder was collected in canvas bag attached at rear cover of combine harvester for 30s. Unthreshed grains were segregated manually from the stalk to know the threshing efficiency.

2.10. Analysis of Variance (ANOVA) for Visible and Invisible Losses

AS, CC, CS as well as their interaction for visible and invisible grain losses was carried out following analysis of variance (ANOVA).

2.11. Statistical Analysis

Analysis of the data was done with Statistical Package for Social Sciences (SPSS, Version 22.0) considering the main effects as well as two factor interactions. The factor means were computed and tested at 5 % level of significance.

3. Results and Discussion

3.1. Grain Losses and Threshing Efficiency during 2017

Both the visible and invisible losses increased with more number of spikes arrangements as well as with the increased CS whereas, higher CC was related with lowered grain damage and *vice-versa*. AS, CC, CS as well as the interaction between AS and CC considerably contributed to the measurement of visible loss whereas, the interaction of CS with AS and CC had non-significant interaction (Table 3). Similarly, invisible grain loss was significantly related with the AS, CC and CS besides, interactions among all the three factors have non-significant contribution to the invisible loss (Table 3). During 2017, the mean grain loss was 4.03%, 4.83% and 5.49% respectively under AS1, AS2 and AS3. The grain loss was minimum *i.e.*, 4.05% ± 0.34% (visible) and 20.89% ± 2.44% (invisible), under AS1. Conversely, these losses were maximum 5.49% ± 0.33% and 28.07% ± 3.21%, respectively under AS3. However with 4.83% ± 0.32% and 26.30% ± 2.20%, the visible and invisible grain loss of AS2 held between the AS1 and the AS3 (Table 4). Thus, the results of the analysis indicated high grain loss with more number of spike arrangement on the tangential cylinder and *vice-versa*. Similarly, the grain loss pattern was similar in different CC spacing arrangement. Under AS1, the highest grain loss (3.89% - 4.53%) was recorded in CS1 followed by 3.72% - 4.36% in CC2 and 3.50% - 4.12% in CC3, respectively. The combination of the AS and CC levels revealed that the range of the grain loss was 4.73% - 5.33%, 4.51% - 5.18% and 4.29% - 4.79%, respectively under CC1, CC2 and CC3. The arrangement of 44 spikes responded into 28.9% invisible grain loss that was lowest in comparison to the corresponding grain loss of 26.3 and 28.0% in the AS2 and AS3, respectively. Among different levels of the spike arrangements, maximum grain loss (5.04% ± 0.33% and 27.11% ± 3.21%) was recorded in CS1, as compared to CS2 (4.77% ± 0.32% and 25.19% ± 2.20%). Contrarily, the highest clearance in CC3 was responsible for lowest grain loss (visible: 4.56% ± 0.34%; invisible: 22.96% ± 2.44%) over CC1 and CC2 (Figure 1 and Figure 2). Therefore, looking to the minimum visible and invisible grain damages by 3.5% and 17.3% respectively, the combination of the AS1 and AC3 with CS1 may be suitably used for further optimization. The results of present research was in good conformity with the finding of [24] who recorded maximum visible loss upto 8.1% while, the invisible grain loss has been reported upto 28% by [25].

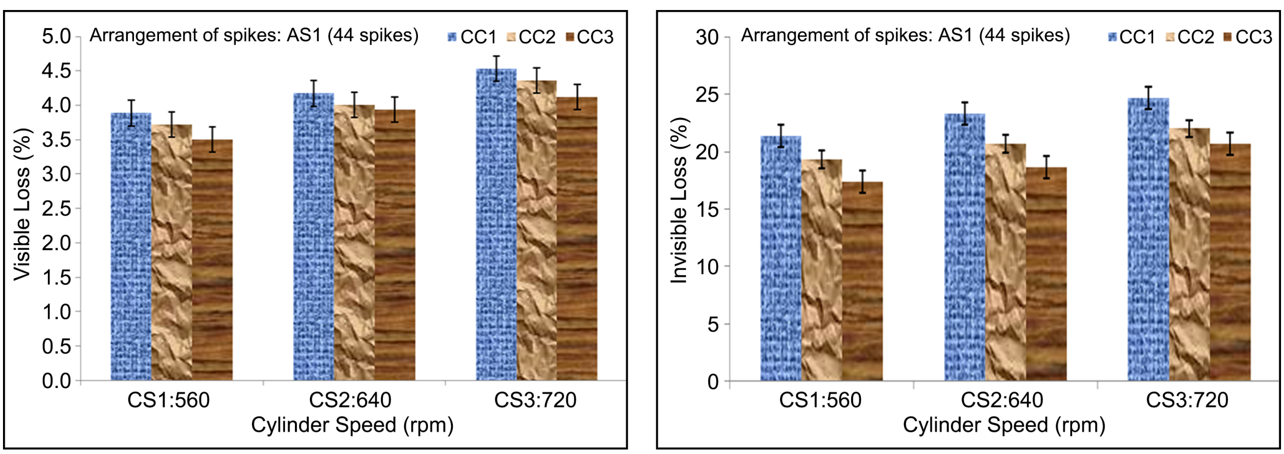

Figure 1. Variation in visible and invisible loss with AS, CC and CS during 2017.

Table 3. ANOVA for visible and invisible losses of Basmati rice (PR-1121) during 2017.

Source	DF	Sum of squares		Mean square		F value		P value		S/NS	
		Visible loss (%)									
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
AS	2	28.187	32.118	14.093	16.059	2205.62	1110.20	<0.0001	<0.0001	S	S
CC	2	3.207	3.391	1.603	1.696	250.95	117.23	<0.0001	<0.0001	S	S
CS	2	4.729	12.908	2.365	6.454	370.05	446.18	<0.0001	<0.0001	S	S
AS*CC	4	0.109	0.971	0.027	0.243	4.28	16.78	0.0045	<0.0001	S	S
AS*CS	4	0.035	3.107	0.009	0.777	1.35	53.71	0.2622	<0.0001	NS	S
CC*CS	4	0.063	0.120	0.016	0.030	2.45	2.08	0.0569	0.0964	NS	NS
		Invisible loss (%)									
AS	2	756.247	226.074	378.123	113.037	134.80	38.81	<0.0001	<0.0001	S	S
CC	2	232.691	266.667	116.346	133.333	41.48	45.78	<0.0001	<0.0001	S	S
CS	2	118.914	150.222	59.457	75.111	21.20	25.79	<0.0001	<0.0001	S	S
AS*CC	4	27.457	13.037	6.864	3.259	2.45	1.12	0.0575	0.3574	NS	NS
AS*CS	4	0.790	9.481	0.198	2.370	0.07	0.81	0.9907	0.5220	NS	NS
CC*CS	4	5.235	7.111	1.309	1.778	0.47	0.61	0.7600	0.6570	NS	NS

Where, S = significant; NS = non significant.

Table 4. Mean grain loss of Basmati rice (PUSA Basmati-1121) during 2017.

Variables	Visible loss (%)	Invisible loss (%)	Threshing efficiency (%)
	AS (Arrangement of spikes)		
AS1 (44)	$4.05^{c} \pm 0.34$	$20.89^{b} \pm 2.44$	$99.32^{c} \pm 0.47$
AS2 (68)	$4.83^{b} \pm 0.32$	$26.30^{a} \pm 2.20$	$99.77^{b} \pm 0.33$
AS3 (136)	$5.49^{a} \pm 0.33$	$28.07^{a} \pm 3.21$	$99.89^{a} \pm 0.17$
	CC (Concave clearance)		
CC1 (13-9 mm)	$5.04^{a} \pm 0.33$	$27.11^{a} \pm 3.21$	$99.85^{a} \pm 0.17$
CC2 (15-11 mm)	$4.77^{b} \pm 0.32$	$25.19^{b} \pm 2.20$	$99.71^{b} \pm 0.33$
CC3 (17-13 mm)	$4.56^{c} \pm 0.34$	$22.96^{c} \pm 2.44$	$99.42^{c} \pm 0.47$
	CS (Cylinder speed)		
CS1 (560 rpm)	$4.47^{c} \pm 0.34$	$23.56^{c} \pm 2.44$	$99.40^{c} \pm 0.47$
CS2 (640 rpm)	$4.84^{b} \pm 0.32$	$25.19^{b} \pm 2.20$	$99.70^{b} \pm 0.33$
CS3 (720 rpm)	$5.06^{a} \pm 0.33$	$26.52^{a} \pm 3.21$	$99.88^{a} \pm 0.17$

Mean values followed with different superscripts are significantly different ($p < 0.05$) using Tukey's test.

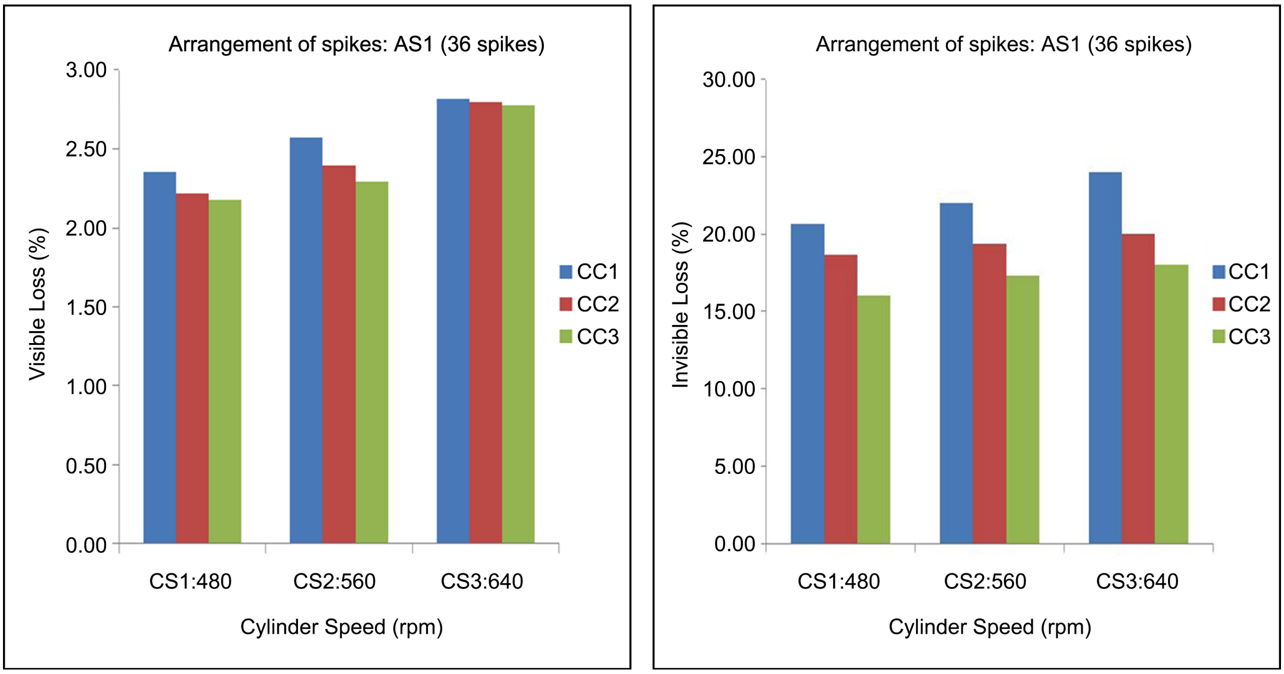

Figure 2. Visible and invisible loss on AS, CC and CS during 2018.

High threshing efficiency was recorded for different treatment combinations. In general, lower the visible/invisible grain damages, higher the threshing efficiency of the combine machines. Results of the analysis (**Table 4**) clearly revealed that the threshing efficiency was maximum *i.e.*, 99.89% ± 0.17% in AS3 that was minimum (99.32% ± 0.47%) in AS1 with respect to AS2 (99.77% ± 0.33%). Thus, minimum and maximum threshing efficiency was under CC3 (99.42 ± 0.47) and CC1 (99.85 ± 0.17), respectively. CS3 (720 rpm) exerted maximum threshing efficiency *i.e.*, 99.88 ± 0.17 followed by CS2 (99.70% ± 0.33%) and CS1 (99.40% ± 0.47%), respectively.

3.2. Grain Losses and Threshing Efficiency during 2018

At the time of threshing efforts were made to minimize the grain damage. In this regards [26] opined that the total grain loss should not be more than 3% of the total crop yield the grain losses are negatively associated with the world population feeding capacity [27]. The tangential threshing system is more aggressive and it causes a higher level of mechanical damaging of grains in comparison of the axial system [28]. While, the lesser rotor speed and the higher concave gap in the conventional combines results into lower damage [29].

The mean visible loss of 0.7% was lowest for spikes in AS1 that was 1.2 and 2.2% for the AS2 and AS3, respectively. Similarly, the invisible losses for the AS1, AS2 and AS3 were 19.6%, 22.5% and 23.5%, respectively with corresponding threshing efficiency of 99.3%, 99.8% and 99.9%. In AS1, the mean visible and invisible losses were 0.79% and 22.22% under CC1; 0.68% and 19.33% under CC2; and 0.62% and 17.11% under CC3, respectively. Thus, high concave clearance (CC1) resulted into lower grain losses and the lesser damage of the grains was related with the high threshing efficiency of the harvester. In AS2, respective mean losses were 1.48% and 24.0%; 1.08% and 23.11%; and 1.01% and 20.44%. These were 2.68% and 26%; 2.04% and 23.11%; and 1.91% and 21.33%, respectively under AS3 (**Table 5**). Average threshing efficiency was 99.6% in different operations. Increase in the CS simultaneously enhanced the threshing efficiency and *vice-versa.* High threshing efficiency was associated with the more rpm values. Already, it has been confirmed by many previous researchers that the fan speed, CS and CC considerably influence the threshing efficiency of a mechanical thresher [30] [31] [32] [33].

In comparison of 2017, grain damage loss was considerably minimized after optimization of the combine harvester during 2018. The visible grain losses were in the range of 76% - 89%, 62% - 82% and 43% - 83% under AS1, AS2 and AS3, respectively while the invisible losses were 3% - 13%, 7% - 23% and 13% - 22%, respectively (**Table 6**). Thus after modification in operational parameters in the machine, the average visible and invisible grain losses may be saved by 83% and 6% in AS1; 76% and 15% in AS2; and 60% and 16% in AS3. Optimization of combine harvester was able to save the visible grain damage by 60% to 83% and invisible grain damage by 6% to 16%, respectively. In proportion to the grain damage avoidance, the threshing efficiency was decreased by 0.01% to 0.02% in second year.

Table 5. Mean grain loss of Basmati rice (PUSA Basmati-1121) during 2018.

Variables	Visible loss (%)	Invisible loss (%)	Threshing efficiency (%)
		Arrangement of spikes	
AS1: (36)	$2.50^{c} \pm 0.25$	$19.56^{b} \pm 3.00$	$99.31^{c} \pm 0.47$
AS2: (44)	$2.99^{b} \pm 0.41$	$22.52^{a} \pm 2.70$	$99.75^{b} \pm 0.33$
AS3: (52)	$4.00^{a} \pm 0.80$	$23.48^{a} \pm 2.86$	$99.88^{a} \pm 0.17$
		CC: Concave clearance	
CC3: (19 - 15 mm)	$2.98^{c} \pm 0.25$	$19.63^{c} \pm 3.00$	$99.40^{c} \pm 0.47$
CC2: (17 - 13 mm)	$3.07^{b} \pm 0.41$	$21.85^{b} \pm 2.70$	$99.70^{b} \pm 0.33$
CC1: (15 - 11 mm)	$3.45^{a} \pm 0.80$	$24.07^{a} \pm 2.86$	$99.84^{a} \pm 0.17$
		CS: Cylinder speed	
CS1: (480 rpm)	$2.68^{c} \pm 0.25$	$20.22^{c} \pm 3.00$	$99.39^{c} \pm 0.47$
CS2: (560 rpm)	$3.16^{b} \pm 0.41$	$21.78^{b} \pm 2.70$	$99.68^{b} \pm 0.33$
CS3: (640 rpm)	$3.66^{a} \pm 0.80$	$23.57^{a} \pm 2.86$	$99.87^{a} \pm 0.17$

Mean values followed with different superscripts are significantly different ($p < 0.05$) using Tukey's test.

Table 6. Visible and invisible losses verses threshing efficiency during 2017 and 2018.

Parameters			Visible loss	Invisible loss	Threshing efficiency	Visible loss	Invisible loss	Threshing efficiency	Visible loss	Invisible loss	Threshing efficiency
				2017			2018			Percent difference	
AS1	CC1	CS1	3.89	21.33	99.31	0.57	20.67	99.29	85.35	3.09	0.020
		CS2	4.17	23.33	99.79	0.79	22.00	99.77	81.06	5.70	0.020
		CS3	4.53	24.67	99.93	1.02	24.00	99.92	77.48	2.72	0.010
	CC2	CS1	3.72	19.33	98.78	0.43	18.67	98.76	88.44	3.41	0.020
		CS2	4.01	20.67	99.30	0.61	19.33	99.28	84.79	6.48	0.020
		CS3	4.36	22.00	99.91	1.00	20.00	99.90	77.06	9.09	0.010
	CC3	CS1	3.50	17.33	98.70	0.38	16.00	98.69	89.14	7.67	0.010
		CS2	3.94	18.67	98.78	0.49	17.33	98.76	87.56	7.18	0.020
		CS3	4.12	20.67	99.40	0.99	18.00	99.39	75.97	12.92	0.010
AS2	CC1	CS1	4.73	26.00	99.86	0.91	22.00	99.84	80.76	15.38	0.020
		CS2	5.13	27.33	99.91	1.50	23.33	99.90	70.76	14.64	0.010
		CS3	5.33	28.67	99.97	2.03	26.67	99.96	61.91	6.98	0.010
	CC2	CS1	4.51	25.33	99.82	0.81	21.33	99.80	82.04	15.79	0.020
		CS2	4.89	26.67	99.85	1.01	22.67	99.83	79.35	15.00	0.020
		CS3	5.18	28.00	99.94	1.43	25.33	99.93	72.39	9.54	0.010
	CC3	CS1	4.29	23.33	98.87	0.76	18.00	98.85	82.28	22.85	0.020
		CS2	4.63	25.33	99.80	0.93	21.33	99.78	79.91	15.79	0.020
		CS3	4.79	26.00	99.92	1.34	22.00	99.90	72.03	15.38	0.020
AS3	CC1	CS1	5.45	28.00	99.94	2.10	24.00	99.92	61.47	14.29	0.020
		CS2	5.79	31.33	99.97	2.43	26.00	99.96	58.03	17.01	0.010
		CS3	6.18	33.33	99.98	3.51	28.00	99.97	43.20	15.99	0.010
	CC2	CS1	5.20	27.33	99.92	1.09	21.33	99.91	79.04	21.95	0.010
		CS2	5.46	28.00	99.95	2.32	22.67	99.94	57.51	19.04	0.010
		CS3	5.62	29.33	99.96	2.71	25.33	99.95	51.78	13.64	0.010
	CC3	CS1	5.00	24.00	99.43	0.87	20.00	99.41	82.60	16.67	0.020
		CS2	5.30	25.33	99.93	2.16	21.33	99.92	59.25	15.79	0.010
		CS3	5.45	26.00	99.94	2.69	22.67	99.93	50.64	12.81	0.010

4. Conclusion

Both the visible and invisible losses increased with more number of spikes arrangements as well as with the increased CS whereas, higher CC was related with lowered grain damage and *vice-versa*. During 2017, the mean visible grain loss was 4.03%, 4.83% and 5.49%, respectively under AS1, AS2 and AS3 while, invisible losses were 28.9%, 26.3% and 28.0% respectively. During 2018, visible grain losses were 76% - 89%, 62% - 82% and 43% - 83% under AS1, AS2 and AS3, but the invisible losses were 3% - 13%, 7% - 23% and 13% - 22%, respectively. Thus, optimization of combine harvester was able to save the visible grain damage by 60% to 83% and invisible grain damage by 6% to 16%, respectively.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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