



Optimization of combine and crop parameters for harvesting of scented and non-scented paddy (*Oryza Sativa*) by head feed combine

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ABSTRACT

A head feed combine was evaluated for optimization of combine parameters, viz. cylinder speed (14.42, 15.53 and 16.64 m/s), forward speed (3.5, 4.0 and 4.5 km/h), and crop parameter, viz. grain moisture content (18.1 to 22.4%) in relation to threshing efficiency, cleaning efficiency and total grain losses for scented and non-scented paddy (*Oryza sativa* L.) varieties. Moisture content of 18.1%, cylinder speed of 15.53 m/s and forward speed of 4.0 km/h was found optimum for harvesting of scented paddy variety Pusa 1121, whereas moisture content of 18.1%, cylinder speed of 16.64 m/s and forward speed of 4.5 km/h was found optimum for harvesting of non-scented paddy variety HKR 127.

Key words: Cleaning efficiency, Combine, Grain losses, Paddy, Threshing efficiency

Paddy (*Oryza sativa* L.) is one of the most important crop for food security in India, contributing significantly towards providing food and livelihood for 130 million people. The area under paddy cultivation in India is around 44 mha, which is largest in the world against total area of 160 mha. The total rice production of the world in 2014 was 742 million tonnes, out of which 105 million tonnes was produced in India (Anonymous 2015).

In paddy cultivation, harvesting and threshing are laborious operations and require about 150-200 man-h/ha (Veerangouda *et al.* 2010). Traditionally, paddy is harvested by manual labour using sickles/reaper followed by threshing manually or by stationary power thresher. Due to the non-availability of labours, crop harvesting is often delayed, which exposes the crop to vagaries of nature. Timely harvesting is utmost important, as delayed harvesting leads to a considerable loss of grain and straw, owing to over maturity resulting in loss of grains by shattering. It also hampers the seed bed preparation and sowing operations for the next crop. The paucity of labour is forcing the farmers to go for crops, which are less labour intensive and more remunerative. Therefore, an efficient method of harvesting and threshing of rice is the immediate need.

considering timeliness of operations a the main criterion, the use of combine harvesters for harvesting and threshing most appropriate.

Combine harvesters is have rasp-bar or spike tooth type longitudinal drum and straw walker. The conventional tangential threshing unit mostly works by impact and due to higher moisture content of paddy, the percentage of broken grains increases. To overcome this problem axial flow combines were introduced, in which crop advances through the threshing mechanism in a direction parallel to the axis of rotor resulting in less grain damage. Another development in axial flow combines are the introduction of head feed combines. In head feed combine only the head parts of the crop comes in contact with the threshing drum. This combine also overcomes the problem of straw handling. It can process paddy straw in different ways, viz. windrow them in an orderly manner or in bundles or cut them in even length and spread them uniformly on ground, which as can be used mulch for succeeding crop.

It is estimated that more than 50% area under rice cultivation is combine harvested and it is increasing continuously due to shortage of farm labour. The majority of left over rice straw is burnt in the field, which results in huge loss of plant nutrients, organic matter and degradation of soil properties. Straw burning results in almost complete loss of nitrogen, along with about 25, 20 and 60% losses of phosphorous, potassium and sulphur, respectively. In addition to these, burning causes severe air pollution, badly affecting the human and animal health. It has been estimated that one ton of straw on burning release 3 kg particulate matter, 60 kg CO, 1460 kg CO₂, 199 kg ash and 2 kg SO₂ (Gupta *et al.* 2004). This affects regional environment

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which also has linkage with global climate change.

The head feed combine cuts the crop from very near to the ground and spread the straw uniformly in the field in small pieces, which can be easily handled either by retaining the straw as mulch on the ground or incorporating it in the soil. Another benefit of using the head feed combine is that it can drop the straw in windrow or in bundles, which can be easily collected by manual labour or by the straw balers. The performance of combines depends critically on straw throughput and grain losses. The threshing effectiveness and losses of combine harvester are greatly influenced by machine parameters, viz. cylinder type, cylinder speed, number of crop rotation, feed rate, method of feeding and forward speed of operation. Crop parameters, viz. moisture content of grain and straw, green matter present at impurity and grain-straw ratio and environmental factors such as temperature, humidity also influence the performance of combine harvester. Thus, there is a need to evaluate and optimize the combine parameters for efficient harvesting of paddy crop.

MATERIALS AND METHODS

The head feed combine (DSM 72) having loop type threshing mechanism (specifications are presented in Table 1), was evaluated for optimization of combine parameters, viz. cylinder speed, forward speed, and crop parameter, viz. grain moisture content in relation to threshing efficiency, cleaning efficiency and total grain losses for scented paddy variety Pusa 1121 and non-scented paddy variety HKR - 127. The experimental variables are presented in Table 2. This study was conducted in Himmatpura (Fatehabad), Haryana during November 21-28, 2014. The test was conducted broadly as per BIS test codes. The data were quantified according to standards laid down and tabulated to draw meaningful inferences. The data for threshing efficiency, cleaning efficiency and grain losses were analyzed using a Randomized Block Design (RBD). ANOVA was calculated and the influence of each variables and their interaction were tested at 5% level of significance using OPSTAT programme (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Threshing efficiency in scented paddy Pusa 1121

The prediction equation for the threshing efficiency of scented paddy variety Pusa 1121 worked out using multiple regression technique is:

$$T_E = 106.79 - 0.448 M_C - 0.207 F_S + 0.167 C_S \quad (R^2 = 0.99) \quad (i)$$

where, M_C = Moisture content in grains, F_S = Forward speed, C_S = Cylinder speed, T_E = Threshing efficiency (%), R^2 = Multiple coefficient of determination (Significant at $P=0.05$).

The regression coefficient of grain moisture content and forward speed was negative in equation (i), which indicated that increase of these variables resulted in decrease in threshing efficiency (Table 3). The positive value of regression coefficients of cylinder speed indicated

Table 1 Technical specification of head feed combine harvester

Dimension (mm)	L × W × H × W	4445 × 1910 × 2635 × 3130
Engine	Model	E4DE-T
	Engine type	Water-cooled, 4-cylinder, DI turbo
	Total displacement (CC)	2955
	Power/Revolutions (hp/rpm)	71/2700
Engine Crawler	Fuel tank capacity (L)	67
	Center distance (mm)	1030
	Width × ground contact (mm)	450 x1580
	Contact pressure (kgf/cm ²)	0.22
Driving system	Transmission Type	HST servo control
	Range	3-stage
	The type of turn	Brake soft spin turn
	Number of reaped crops	4
Reaping unit	Reaping interval (mm)	1450~1500
	Width of reaping cutting blade (mm)	1450
	Type of reaping cutting blade	Two blades sliding cutting
	Type of speed	Speed-synchronized + elevator (3)
Threshing unit	Threshing type	Half feeding, single trash drum
	Threshing cylinder	Loop type
	Threshing cylinder, Diameter × width (mm)	424 × 900
	Processing cylinder (1), Diameter × width (mm)	140 × 725
	Processing cylinder (2), Diameter × width (mm)	140 × 100
	Sieve case, width × diameter (mm)	665 × 1550
Grain discharging system	Tank capacity (kg)	1400
	Turning radius (degree) – turning type	270 - Electric motor turning type

Table 2 Range of independent parameters selected for the study

Parameter	Range
Moisture content, M1–M2–M3 (%)	22.3-22.4 × 20.3-20.4 × 18.1
Forward speed, F1–F2–F3 (km/h)	3.5 × 4.0 × 4.5
Cylinder speed, C1–C2–C3 (m/s)	14.42 × 15.53 × 16.64

Table 3 Crop and field parameters of scented and non-scented paddy varieties

Particulars	Scented paddy varieties	Non-scented paddy varieties
Variety	Pusa 1121	HKR 127
Soil moisture content, (%)	15.2	15.5
Bulk density of soil (w.b) (g cm ³)	1.49	1.49
Grain moisture content (w. b), (%)	18.1-22.4	18.1-22.3
Straw moisture content (w. b), (%)	52.5	52.8
Plant height, (cm)	115	93
Length of panicle, (cm)	18	17.5
No. of grains/panicle	76	84
Number of hill/m.	23	22
Straw-grain ratio	1.26	1.21

that threshing efficiency increased with increase in cylinder speed. The multiple coefficient of determination indicated that these variables contributed 99% in total variation in threshing efficiency in this variety. The effect of interactions of variables, viz. grain moisture-forward speed, grain moisture-cylinder speed and cylinder speed-forward speed were significant, but the interactions of grain moisture-forward speed-cylinder speed were found to be non-significant (Table 4). The threshing efficiency was found directly proportional to cylinder speed and it was negatively correlated with moisture content and forward speed. It increased from 97.176 to 99.808% as the grain moisture decreased from 22.4 to 18.1% and cylinder speed

increased from 14.42 m/s to 16.64 m/s at forward speed of 4.5 km/h (Table 4). Increased threshing efficiency at higher cylinder speed was probably due to increased impact force on the grains. The minimum threshing efficiency at higher moisture content may be due to the fact that the grains became slightly elastic and more impact force is required for the grain to get detached from the panicle. The results are in conformity with those reported by Manes *et al.* (2015) in axial flow threshing system.

Cleaning efficiency in scented paddy Pusa 1121

The prediction equation for the cleaning efficiency of scented paddy variety Pusa-1121 worked out using multiple regression technique is:

$$C_E = 105.47 - 0.434 M_C - 0.012 F_S + 0.125 C_S \quad (R^2 = 0.98) \quad (ii)$$

where, C_E = Cleaning efficiency (%), R^2 = Multiple coefficient of determination (Significant at $P = 0.05$)

The regression coefficients of grain moisture content and forward speed were negative in equation (ii), indicating that increase of these variables resulted in the decrease in cleaning efficiency. The positive value of regression coefficient of cylinder speed indicated that cleaning efficiency increased with the increase in cylinder speed. The multiple coefficient of determination indicated that these variables contributed 98% in total variation of cleaning efficiency in Pusa 1121.

The effect of interactions of variables, viz. grain moisture-forward speed and grain moisture-cylinder speed were significant but the interactions of cylinder speed-forward speed and grain moisture-forward speed-cylinder speed were non-significant (Table 5). The cleaning efficiency was minimum at higher moisture content, lower forward

Table 4 Effect of grain moisture, forward speed and cylinder speed on threshing efficiency in scented paddy variety Pusa-1121

Cylinder speed (m/s)	Grain moisture (%)												
	Forward speed (Km/h)				Forward speed (Km/h)				Forward speed (Km/h)				
	22.4				20.3				18.1				
	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	
14.42	97.674	97.445	97.176	97.432	98.515	98.456	98.417	98.463	99.577	99.548	99.518	99.548	
15.53	97.874	97.545	97.346	97.588	98.715	98.641	98.637	98.664	99.757	99.738	99.718	99.738	
16.64	97.974	97.785	97.576	97.778	99.045	98.976	98.877	98.966	99.807	99.808	99.808	99.808	
Mean (Forward speed)	97.841	97.592	97.366		98.758	98.691	98.644		99.714	99.698	99.681		
Mean (Grain moisture)	97.599				98.698				99.698				
Mean (Forward speed)	(3.5 km/h) = 98.771				(4.0 km/h) = 98.660				(4.5 km/h) = 98.564				
Mean (Cylinder speed)	(14.42 m/s) = 98.481				(15.53 m/s) = 98.663				(16.64 m/s) = 98.851				
CD (P = 0.05)	MC = 0.049				FS = 0.049				CS = 0.049				
Interaction	MC × FS = 0.085				MC × CS = 0.085				FS × CS = 0.085				MC × FS × CS = NS

Table 5 Effect of grain moisture, forward speed and cylinder speed on cleaning efficiency in scented paddy variety Pusa-1121

Cylinder speed (m/s)	Grain moisture (%)															
	Forward speed (Km/h)				Forward speed (Km/h)				Forward speed (Km/h)							
	22.4				20.3				18.1							
	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)				
14.42	97.251	97.352	96.803	97.135	98.021	98.121	97.983	98.042	98.851	98.89	98.91	98.883				
15.53	97.412	97.504	96.955	97.290	98.19	98.292	98.15	98.211	99.053	99.144	99.131	99.109				
16.64	97.392	97.480	97.171	97.348	98.123	98.241	98.102	98.155	99.091	99.121	99.112	99.108				
Mean (Forward speed)	97.352	97.445	96.976		98.111	98.218	98.078		98.998	99.052	99.051					
Mean (Grain moisture)	97.258				98.136				99.034							
Mean (Forward speed)	(3.5 km/h) = 98.154				(4.0 km/h) = 98.238				(4.5 km/h) = 98.035							
Mean (Cylinder speed)	(14.42 m/s) = 98.020				(15.53 m/s) = 98.203				(16.64 m/s) = 98.204							
CD (P = 0.05)	MC = 0.052				FS = 0.052				CS = 0.0052							
Interaction	MC × FS = 0.090				MC × CS = 0.090				FS × CS = NS				MC × FS × CS = NS			

speed and lower cylinder speed. Cleaning efficiency increased as the grain moisture content decreased from 22.4 to 18.1% and forward speed increased from 3.5 to 4.0 km/h and cylinder speed increased from 14.42 to 15.53 m/s, but as cylinder speed increased from 15.53 to 16.64 m/s and forward speed increased from 4.0 to 4.5 km/h, the cleaning efficiency decreased (Table 5). Lower cleaning efficiency at higher grain moisture may be due difficulties in proper screening because of poor flow of threshed material on sieve (Sangwijit and Chinsuwan, 2010). The results are in conformity with Manes *et al.* (2015) who observed that cleaning efficiency increased with increasing cylinder speed upto a critical level and then decreased with further increase in cylinder speed as throughput increases in axial flow threshing system.

Grain losses in scented paddy Pusa 1121

The prediction equation for the total grain losses due to changes in different variables in scented paddy variety Pusa-1121 worked out using multiple regression technique is:

$$G_L = - 4.199 + 0.407 M_C + 0.150 F_S - 0.137 C_S \quad R^2 = 0.97 \quad \text{(iii)}$$

where, G_L = Total grain losses (%); R^2 = Multiple coefficient of determination (Significant at P = 0.05).

The regression coefficient of cylinder speed was negative in equation (iii), which indicated that increase in cylinder speed resulted in decrease in total grain losses in scented paddy variety Pusa 1121, while, the positive value of regression coefficients of grain moisture content and forward speed indicated that total grain losses increased with the increase in grain moisture and forward speed. The multiple coefficient of determination predicted that these variables contributed 97% in total variation of total grain losses in Pusa 1121.

The effect of interactions of variables, viz. grain

moisture-forward speed, grain moisture-cylinder speed, cylinder speed-forward speed and grain moisture-forward speed-cylinder speed were found significant (Table 6). The total grain losses were maximum at higher moisture content and it decreased as the grain moisture content decreased from 22.4 to 18.1%. It may be due to the reason that more force is required to detach the grain from the panicle at higher grain moisture content that leads to higher unthreshed losses, however, less energy is required to detach the grain from the panicle at lower grain moisture content. The results are in conformity with those reported by Alizadeh and Khodabakhshpour (2010) and Chuan and Chinsuwan (2010).

The total grain losses in Pusa 1121 decreased as we increased the cylinder speed from 14.42 to 15.53 m/s irrespective of the levels of moisture content (Table 7). It might be due to the reason that with an increase in cylinder speed, the number of impacts between grain and cylinder increases, which results in higher threshing and leaving lesser unthreshed grains. Total grain losses increased as we increased the cylinder speed from 15.53 to 16.64 m/s at 18.1% moisture content. It might be due to the fact that at lower moisture content there are lesser unthreshed grains but the damage incurred to grain is more resulting in higher total grain losses. These results are in conformity with Manes *et al.* (2015) and Lashgari *et al.* (2008).

The unthreshed grain losses increased as moisture content and forward speed increased and it decreased as cylinder speed increased (Table 7). It may be due to the reason that at higher seed moisture content, panicle grain attachment strength was higher, which might resulted in increased elastic behavior of crop and reduced effect of impact and frictional forces leading to more unthreshed grains. The broken grain losses increased as cylinder speed increased and moisture content decreased, whereas,

Table 6 Effect of grain moisture, forward speed and cylinder speed on total grain losses in scented paddy variety Pusa-1121

Cylinder speed (m/s)	Grain moisture (%)												
	Forward speed (Km/h)				Forward speed (Km/h)				Forward speed (Km/h)				
	22.4				20.3				18.1				
	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	
14.42	3.269	3.470	3.736	3.492	2.838	2.827	2.893	2.853	1.749	1.638	1.773	1.720	
15.53	3.094	3.375	3.561	3.343	2.633	2.637	2.658	2.643	1.564	1.428	1.618	1.537	
16.64	3.089	3.198	3.328	3.205	2.403	2.397	2.418	2.406	1.598	1.437	1.590	1.542	
Mean (Forward speed)	3.151	3.348	3.542		2.625	2.620	2.656		1.637	1.501	1.660		
Mean (Grain moisture)	3.348				2.634				1.599				
Mean (Forward speed)	(3.5 km/h) = 2.471				(4.0 km/h) = 2.490w				(4.5 km/h) = 2.619				
Mean (Cylinder speed)	(14.42 m/s) = 2.688				(15.53 m/s) = 2.508				(16.64 m/s) = 2.384				
CD (P = 0.05)	MC = 0.007				FS = 0.007				CS = 0.007				
Interaction	MC × FS = 0.013				MC × CS = 0.013				FS × CS = 0.013				MC × FS × CS = 0.022

it decreased as forward speed increased. It might be due to the reason that with an increase in cylinder speed, the number of impacts between grain and cylinder increases resulting in more broken grains. At lower seed moisture content, the less energy was required to detach the grain from the panicle and the surplus energy resulted in more grain breakage. Alizadeh and Khodabakhshipour (2010) also reported that in axial flow threshing system the maximum broken grains of 0.68% was recorded at a speed of 850 rpm and moisture contents of 17%, whereas the least value was obtained at a drum speed of 450 and 550 rpm and moisture content of 23%.

The cutter bar losses increased as moisture content decreased and forward speed increased (Table 7). It might be due to the fact that at lower moisture content, the bonding of grain with the panicle is weak and the grains shattered easily from the panicles after coming in contact with cutter bar. Similarly, at higher forward speed, the shattering of grains are more due to higher impact of cutter bar. However, with decrease in moisture content and increase in forward speed the conveyance losses increases, which are counted towards cutter bar losses in the head feed combine. The results are in conformity with Sangwijit and Chinsuwan (2010) and Abdi and Jalali (2013). The effect of cylinder speed, forward speed and moisture content on threshed grain losses, unthreshed grain losses and broken grain losses on sieve were observed as non-significant. Manes *et al.* (2015) in axial flow threshing system reported similar results.

Threshing efficiency in non-scented paddy HKR 127

The prediction equation for the threshing efficiency due to changes in different variables in non-scented paddy variety HKR 127 worked out using multiple regression

technique is:

$$T_E = 103.914 - 0.368 M_C - 0.175 F_S + 0.189 C_S (R^2 = 0.99)(iv)$$

The regression coefficients of grain moisture content and forward speed were negative in equation (iv), which indicated that increase of these variables resulted in decrease in threshing efficiency. The positive value of regression coefficient of cylinder speed indicated that threshing efficiency increases with the increase in cylinder speed. The coefficient of determination indicated that these variables contributed 99% in total variation of threshing efficiency.

The effect of interactions of variables, viz. grain moisture-forward speed, grain moisture-cylinder speed and cylinder speed-forward speed were found non-significant, but the interactions of grain moisture-forward speed-cylinder speed were significant (Table 8). The threshing efficiency was directly proportional to cylinder speed and it was negatively correlated with moisture content and forward speed. It increased from 97.676 to 99.717% as the grain moisture decreased from 22.3 to 18.1% and cylinder speed increased from 14.42 m/s to 16.64 m/s at forward speed of 4.5 km/h (Table 8). Higher threshing efficiency at higher cylinder speed was probably due to increased impact force on the grains. The minimum threshing efficiency at higher moisture content may be due to the fact that at higher moisture content the grains became slightly elastic and more impact force is required for the grain to get detached from the ear head. The results are in conformity with those reported by Manes *et al.* (2015) in axial flow threshing system.

Cleaning efficiency in non-scented paddy HKR 127

The prediction equation for the cleaning efficiency due to changes in different variables in non-scented paddy

Table 7 Total harvesting losses in scented paddy variety Pusa 1121

Interaction	Collectable losses (%)		Cutter bar losses (%)	Non collectable losses (%)			Total losses (%)	Threshing efficiency (%)
	Unthreshed losses (%)	Broken losses (%)		Sieve losses				
				Threshed losses (%)	Unthreshed losses (%)	Broken losses (%)		
M1F1C1	2.32	0.18	0.302	0.46	0.0061	0.001	3.2691	97.674
M1F1C2	2.12	0.22	0.302	0.445	0.0062	0.001	3.0942	97.874
M1F1C3	2.02	0.33	0.302	0.43	0.006	0.001	3.089	97.974
M1F2C1	2.55	0.15	0.324	0.44	0.0052	0.001	3.4702	97.445
M1F2C2	2.45	0.17	0.324	0.425	0.005	0.001	3.375	97.545
M1F2C3	2.21	0.24	0.324	0.418	0.0053	0.001	3.1983	97.785
M1F3C1	2.82	0.13	0.353	0.428	0.0041	0.001	3.7361	97.176
M1F3C2	2.65	0.145	0.353	0.408	0.0044	0.001	3.5614	97.346
M1F3C3	2.42	0.16	0.353	0.39	0.0042	0.001	3.3282	97.576
M2F1C1	1.48	0.25	0.682	0.42	0.0051	0.001	2.8381	98.515
M2F1C2	1.28	0.28	0.682	0.385	0.005	0.001	2.633	98.715
M2F1C3	0.95	0.42	0.682	0.345	0.0052	0.001	2.4032	99.045
M2F2C1	1.54	0.21	0.702	0.37	0.004	0.001	2.827	98.456
M2F2C2	1.32	0.25	0.702	0.325	0.039	0.001	2.637	98.641
M2F2C3	1.02	0.38	0.702	0.29	0.0041	0.001	2.3971	98.976
M2F3C1	1.58	0.19	0.804	0.315	0.0029	0.001	2.8929	98.417
M2F3C2	1.36	0.24	0.804	0.25	0.003	0.001	2.658	98.637
M2F3C3	1.12	0.29	0.804	0.2	0.0031	0.001	2.4181	98.877
M3F1C1	0.42	0.28	0.865	0.18	0.0028	0.001	1.7488	99.577
M3F1C2	0.24	0.32	0.865	0.135	0.0029	0.001	1.5639	99.757
M3F1C3	0.19	0.42	0.865	0.118	0.0035	0.001	1.5975	99.807
M3F2C1	0.45	0.18	0.885	0.12	0.0019	0.001	1.6379	99.548
M3F2C2	0.26	0.19	0.885	0.09	0.0019	0.001	1.4279	99.738
M3F2C3	0.19	0.25	0.884	0.11	0.002	0.001	1.437	99.808
M3F3C1	0.48	0.14	1.005	0.145	0.0018	0.001	1.7728	99.518
M3F3C2	0.28	0.17	1.005	0.16	0.0017	0.001	1.6177	99.718
M3F3C3	0.19	0.21	1.005	0.182	0.0015	0.001	1.5895	99.809

variety HKR 127 worked out using multiple regression technique is:

$$C_E = 103.085 - 0.354 M_C - 0.066 F_S + 0.157 C_S \quad (R^2 = 0.98) \quad (v)$$

The regression coefficients of grain moisture content and forward speed were negative in equation (v), which indicated that increase of these variables resulted in the decrease in cleaning efficiency. The positive value of regression coefficient of cylinder speed indicated that cleaning efficiency increases with the increase in cylinder speed. The coefficient of determination indicated that these variables contributed 98% in total variation of cleaning efficiency.

The effect of interactions of variables, viz. grain moisture-forward speed, grain moisture-cylinder speed and cylinder speed-forward speed were significant. The interaction of grain moisture-forward speed-cylinder speed was found non-significant (Table 9). The cleaning efficiency

was minimum at higher moisture content, forward speed and lower cylinder speed. Cleaning efficiency increased from 97.158 to 99.140% as the grain moisture content decreased from 22.3 to 18.1%. The cleaning efficiency increased as cylinder speed increased from 14.42 to 16.64 m/s at 18.1% moisture content and forward speed of 4.5 km/h (Table 9). The results are in conformity with Sangwijit and Chinsuwan (2010), who observed that higher grain moisture caused difficulties in proper screening because of poor flow of threshed material on sieve. The results are in conformity with Manes *et al.* (2015) who revealed that cleaning efficiency increased with increased cylinder speed upto a critical level and then decreased with further increase in cylinder speed as throughput increases in axial flow threshing system.

Grain losses in non-scented paddy HKR - 127

The prediction equation for the grain losses due to

Table 8 Effect of grain moisture, forward speed and cylinder speed on threshing efficiency in non-scented paddy variety HKR 127

Cylinder speed (m/s)	Grain moisture (%)												
	Forward speed (Km/h)				Forward speed (Km/h)				Forward speed (Km/h)				
	22.4				20.3				18.1				
	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	
14.42	97.815	97.775	97.676	97.755	98.445	98.346	98.277	98.356	99.347	99.317	99.277	99.314	
15.53	98.145	98.035	97.746	97.975	98.645	98.546	98.467	98.553	99.547	99.487	99.517	99.517	
16.64	98.395	98.195	98.016	98.202	98.875	98.756	98.657	98.763	99.716	99.716	99.717	99.716	
Mean (Forward speed)	98.118	98.002	97.813		98.655	98.549	98.467		99.537	99.507	99.504		
Mean (Grain moisture)	97.978				98.557				99.516				
Mean (Forward speed)	(3.5 km/h) = 98.770				(4.0 km h) = 98.686				(4.5 km/h) = 98.594				
Mean (Cylinder speed)	(14.42 m/s) = 98.475				(15.53 m/s) = 98.682				(16.64 m/s) = 98.894				
CD (P=0.05)	MC = 0.043				FS = 0.043				CS = 0.043				
Interaction	MC × FS = NS				MC × CS = NS				FS × CS = NS				MC × FS × CS = 0.128

changes in different variables in non-scented paddy variety HKR 127 worked out using multiple regression technique is:

$$G_L = -1.141 + 0.285 M_C + 0.094 F_S - 0.178 C_S \quad (R^2 = 0.93) \quad (vi)$$

The regression coefficient of cylinder speed was negative in equation (vi), which indicated that increase of this variable resulted in the decrease in total grain losses. The positive value of regression coefficients of grain moisture content and forward speed indicated that total grain losses increases with the increase in grain moisture and forward speed. The coefficient of determination indicated that these variables contributed 93% in total variation of total grain losses.

The effect of interactions of variables, viz. grain moisture-forward speed, grain moisture-cylinder speed and cylinder speed-forward speed and grain moisture-forward speed-cylinder speed were found significant (Table 10). The total grain losses were maximum at higher moisture content and it decreased as the grain moisture content decreased from 22.3 to 18.1% as unthreshed losses increases because higher force is needed to detach the grain from the panicle at higher grain moisture content. The results are in conformity with those reported by Alizadeh and Khodabakhshipour (2010) and Chuan and Chinsuwan (2010). The total grain losses decreased as we increased the cylinder speed from 14.42 to 16.64 m/s irrespective of

Table 9 Effect of grain moisture, forward speed and cylinder speed on cleaning efficiency in non-scented paddy variety HKR 127

Cylinder speed (m/s)	Grain moisture (%)											
	Forward speed (Km/h)				Forward speed (Km/h)				Forward speed (Km/h)			
	22.3				20.4				18.1			
	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)	3.5	4	4.5	Mean (cylinder speed)
14.42	97.261	97.251	97.158	97.223	97.85	97.78	97.741	97.790	98.681	98.742	98.771	98.731
15.53	97.552	97.48	97.215	97.416	98.011	97.951	97.890	97.951	98.862	98.911	98.992	98.922
16.64	97.78	97.615	97.468	97.621	98.120	98.148	98.121	98.130	98.972	99.012	99.14	99.041
Mean (Forward speed)	97.531	97.449	97.280		97.994	97.960	97.917		98.838	98.888	98.967	
Mean (Grain moisture)	97.420				97.957				98.900			
Mean (Forward speed)	(3.5 km/h) = 98.121				(4.0 km/h) = 98.099				(4.5 km/h) = 98.057			
Mean (Cylinder speed)	(14.42 m/s) = 97.915				(15.53 m/s) = 98.096				(16.64 m/s) = 98.266			
CD (P=0.05)	MC = 0.049											
Interaction	MC × FS = 0.084											

Table 10 Effect of grain moisture, forward speed and cylinder speed on total grain losses in non-scented paddy variety HKR 127

Cylinder speed (m/s)	Grain moisture (%)											
	Forward speed (Km/h)				Forward speed (Km/h)				Forward speed (Km/h)			
	22.3				20.4				18.1			
	3.5	4	4.5	Mean (CS)	3.5	4	4.5	Mean (CS)	3.5	4	4.5	Mean (CS)
14.42	2.981	2.946	3.090	3.006	2.586	2.770	2.821	2.727	1.839	1.755	1.749	1.781
15.53	2.686	2.696	3.012	2.798	2.406	2.478	2.596	2.493	1.639	1.625	1.539	1.601
16.64	2.412	2.561	2.740	2.571	2.236	2.272	2.306	2.271	1.528	1.475	1.339	1.447
Mean (Forward speed)	2.693	2.734	2.947		2.409	2.508	2.574		1.669	1.618	1.542	
Mean (MC)	2.794				2.497				1.610			
Mean (FS)	(3.5 km/h) = 2.257				(4.0 km/h) = 2.286				(4.5 km/h) = 2.354			
Mean (CS)	(14.42 m/s) = 2.504				(15.53 m/s) = 2.297				(16.64 m/s) = 2.097			
CD (P=0.05)	MC = 0.008				FS = 0.008				CS = 0.008			
Interaction	MC × FS = 0.014				MC × CS = 0.014				MC × CS = 0.014			

Table 11 Total harvesting losses in non-scented paddy variety HKR 127

Interaction	Collectable losses (%)			Non collectable losses (%)			Total losses (%)	Threshing efficiency (%)
	Unthreshed losses (%)	Broken losses (%)	Cutter bar losses (%)	Sieve losses				
				Threshed losses (%)	Unthreshed losses (%)	Broken losses (%)		
M1F1C1	2.18	0.14	0.295	0.36	0.0051	0.001	2.9811	97.815
M1F1C2	1.85	0.18	0.295	0.355	0.005	0.001	2.686	98.145
M1F1C3	1.6	0.2	0.295	0.34	0.0052	0.001	2.4412	98.395
M1F2C1	2.22	0.11	0.31	0.3	0.0051	0.001	2.9461	97.775
M1F2C2	1.96	0.14	0.31	0.28	0.0049	0.001	2.6959	98.035
M1F2C3	1.8	0.165	0.31	0.28	0.0051	0.001	2.5611	98.195
M1F3C1	2.32	0.102	0.338	0.325	0.0041	0.001	3.0901	97.676
M1F3C2	2.25	0.115	0.338	0.304	0.0039	0.001	3.0119	97.746
M1F3C3	1.98	0.132	0.338	0.285	0.0042	0.001	2.7402	98.015
M2F1C1	1.55	0.18	0.55	0.3	0.0051	0.001	2.5861	98.445
M2F1C2	1.35	0.22	0.55	0.28	0.0052	0.001	2.4062	98.645
M2F1C3	1.12	0.34	0.55	0.22	0.005	0.001	2.236	98.875
M2F2C1	1.65	0.15	0.615	0.35	0.0042	0.001	2.7702	98.346
M2F2C2	1.45	0.18	0.615	0.228	0.0041	0.001	2.4781	98.546
M2F2C3	1.24	0.192	0.615	0.22	0.004	0.001	2.272	98.756
M2F3C1	1.72	0.12	0.692	0.285	0.0031	0.001	2.8211	98.277
M2F3C2	1.53	0.16	0.692	0.21	0.0032	0.001	2.5962	98.467
M2F3C3	1.34	0.12	0.692	0.15	0.0029	0.001	2.3059	98.657
M3F1C1	0.65	0.25	0.785	0.15	0.003	0.001	1.839	99.347
M3F1C2	0.45	0.28	0.785	0.12	0.0031	0.001	1.6391	99.547
M3F1C3	0.28	0.35	0.785	0.108	0.0042	0.001	1.5282	99.716
M3F2C1	0.68	0.16	0.812	0.1	0.0029	0.001	1.7559	99.317
M3F2C2	0.51	0.21	0.812	0.09	0.0029	0.001	1.6259	99.487
M3F2C3	0.28	0.28	0.812	0.09	0.0038	0.001	1.4668	99.716
M3F3C1	0.72	0.09	0.855	0.08	0.003	0.001	1.749	99.277
M3F3C2	0.48	0.12	0.855	0.08	0.0026	0.001	1.5386	99.517
M3F3C3	0.28	0.12	0.855	0.08	0.0026	0.001	1.3386	99.717

moisture content (Table 10). It might be due to the reason that the number of impacts between grain and cylinder increases with increase in cylinder speed resulting in more threshing and less unthreshed grains. These results are in line with earlier work carried out by Manes *et al.* (2015) and Lashgiri *et al.* (2008).

The unthreshed grain losses increased as moisture content and forward speed increased and decreased as cylinder speed increased (Table 11). It may be due to the reason that at higher seed moisture content, panicle grain attachment strength was higher causing increased elastic behavior of crop and resulted in reduced effect of impact forces and ultimately more unthreshed grains. The broken grain losses increased as cylinder speed increased and moisture content decreased, whereas, broken grains decreased as forward speed increased as the number of impacts between grain and cylinder increases with increase in cylinder speed resulted in more broken grains. At lower seed moisture content, less energy was required to detach the grain from the panicle and the surplus energy resulted in more grain breakage. Alizadeh and Khodabakhshpour (2010) also reported that in axial flow threshing system the maximum broken grains of 0.68% was recorded at a speed of 850 rpm and moisture contents of 17%, whereas the least value was obtained at a drum speed of 450 and 550 rpm and moisture content of 23%.

The cutter bar losses increased as moisture content decreased, and forward speed increased as grains shattered easily from the panicles after coming in contact with cutter bar at lower moisture content because of weak bonding of grain with the panicle (Table 11). Similarly, at higher forward speed the shattering of grains was higher due to higher impact of cutter bar to cut the rice stem. However, with decrease in moisture content and forward speed the conveyance losses increases, which are counted towards cutter bar losses in this head feed paddy combine. The results are in conformity with Sangwijit and Chinsuwan (2010) and Abdi and Jalali (2013). The effect of cylinder speed, forward speed and moisture content were not observed significant on threshed, unthreshed and broken grain losses on sieve. Manes *et al.* (2015) also reported similar findings in axial flow threshing system.

From the above, it can be inferred that moisture content of 18.1%, cylinder speed of 15.53 m/s and forward speed of 4.0 km/h is optimum for harvesting of scented paddy variety Pusa 1121, whereas, moisture content of 18.1%,

cylinder speed of 16.64 m/s and forward speed of 4.5 km/h is optimum for harvesting of non-scented paddy variety HKR-127. Moisture content is the most important factor influencing threshing efficiency, cleaning efficiency and total grain losses followed by cylinder speed and forward speed in both scented and non-scented varieties.

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