Indian Journal of Agricultural Sciences **92** (3): 344–7, March 2022/Article
https://doi.org/10.56093/ijas.v92i3.122683

Optimization of operational parameters for dust separation system of wheat straw combine using sieve setup

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Received: 15 October 2020; Accepted: 01 November 2021

ABSTRACT

Straw obtained after mechanical harvesting with combine contains foreign matter like dust which makes it unhealthy for milch animals. An attempt was made to develop a dust separation system for wheat straw combine at Department of Farm Machinery and Power Engineering, PAU Ludhiana during 2019–20. The study involved optimisation of operational parameters for effective dust separation system in wheat straw combine and evaluation of optimized dust separation system under field conditions. The laboratory evaluation of sieve setup was carried for three sieve sizes (3 mm, 4mm, 5 mm), three ossciliations (300, 350, 400 spm) and two residue load conditions (0.572 kg, 0.738 kg). Sieve setup consisted of variable drive system with control unit and electric motor of 2.0 kW having rotational speed of 1500 rpm. The operational parameter, sieve opening size ϕ5 mm and sieve oscillations 400 spm was found better to give the straw quality parameters such as ash content, acid insoluble ash and dust concentration in the range of 8.60–8.77%, 5.14–5.90% and 5.44–6.30%, respectively. The developed system will help in reducing the dust concentration in the wheat straw during harvesting.

Keywords: Acid insoluble ash, Dust concentration, Dust separation system, Wheat straw combine

Wheat is the major cereal crop of India contributing 13% to world's wheat production. In India, Punjab is one of the major wheat growing state with 3.51 million ha and a productivity of 5090 kg/ha as compared to national average of 3371 kg/ha (Anonymous 2019). Harvesting is a major operation in wheat production system performed either manually, mechanically or combination of both. Wheat straw left after combine harvesting is the major feed stock source for milch animals. To retrieve this loose wheat straw with leftover standing stubbles, locally manufactured wheat straw combine is employed. The straw obtained from wheat straw combines contains foreign matter like dust which makes it unhealthy for milching animals (Bhardwaj 2008). For removal of dust from straw different separation systems have been designed. The optimum values for mechanical separation of wheat straw with independent parameters, viz. straw retention time, sieve opening, strokes per minute and straw bed thickness were 40 s, 0.208 mm, 160 rpm and 50 mm, respectively (Bhardwaj 2008). It was reported that as the oscillations increase, mass of separation increased and there is need to increase sieve oscillations to maintain straw flow and straw depth at desired level (Dhimate 2014). The wheat straw quality parameters like average straw length, total ash content and acid insoluble ash obtained from modified straw bruising and sieving unit were found to be 26, 14 and 19% more respectively as compared to the quality of wheat straw obtained from harambha thresher (Dhimate 2014). Wheat straw obtained from combine harvester had 13.7% total ash content and 6.61% acid insoluble ash. While straw produced from the stationary wheat thresher had only 8.85% ash content and 4.09% insoluble ash content which is very near to the recommended values (Bhardwaj and Mahal 2014). Ali (2020) developed an integral dust separation system for wheat straw combine. In order to optimize the best suited parameters for field evaluation of integral dust separation system of wheat straw combine, laboratory study was carried out using selected independent parameters and their effect on dependent parameters.

MATERIALS AND METHODS

Present study was carried at Farm Machinery Testing Centre, of Punjab Agricultural University, Ludhiana, Punjab during 2019–20. The study involved development of experiemtal set-up, optimization of operational parameters for dust separation system and field evlaution of developed dust separation system.

Laboratory seive set up: A customized experimental set-up was developed for laboratory evaluation of sieves

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of different sizes at varying oscillations. The variable drive set up consisted of control unit and electric motor (2.0 kW, 220 V) having rotational speed of 1500 rpm. Sieve oscillations were regulated from the control unit to slider crank mechanism via electric motor. A rectangular mild steel sheet sieve box of size 600 mm × 380 mm × 160 mm having thickness of 2.0 mm was used for laboratory evaluation of the sieves. The pointer scale of variable speed unit ranged from 0–260 which produced the change in electric motor output rpm. The crank was connected to sieve using pitman.

Independent parameters: Dust separation of bruised straw was carried out under laboratory condition to optimize the parameters for effective dust separation system. The various independent and dependent parameters pertaining to the laboratory evaluation are presented in Table 1. The straw load was selected for the laboratory study was based on the actual load observed in the field. A load of 0.572 and 0.738 kg corresponding to the assumed low and high field straw availability of 0.35 kg/m^2 and 0.45 kg/m^2, respectively was selected for a Sieve effective area 0.1728 m^2 (Singh *et al.* 2017). The material over the sieve was collected in polythene bags for quality and chemical analysis. Based on preliminary trials three openings of sieve sizes, viz. 3.0 , 4.0 and 5.0 mm having 286, 196 and 168 holes, respectively, in area of 10000 mm^2 were used.

The effective size of sieve was 320 × 540 mm^2. Previous studies showed that sieve should have more than 310 spm to remove dirt in less time (Dhimate 2014). Based on preliminary trials of the developed dust separation system, different levels for oscillations, viz. 300, 350 and 400 spm were selected.

Measurement of dependent paramters: Samples of the bruised straw were collected from the sieve and the trailer during laboratory and field evaluation, respectively. A 10 g of sample was selected randomly and average straw size of bruised straw pieces was calculated. The bruised straw pieces or sticks were measured and divided into length groups (IS 15805–2008). Standard procedure was followed to determine the ash content, acid insoluble ash (IS: 13875-1993) and dust concentration. Ash content was calculated as:

$$\text{Ash content (\%)} = \frac{W_{ca} - W_c}{W_{cd} - W_c} \times 100$$

where W_c, weight of empty crucible (g); W_{cd}, weight of crucible (g)+ dry sample (g); W_{ca}, weight of crucible (g)+ ash (g).

The acid insoluble ash content of bruised straw was calculated as:

$$\text{Acid insoluble ash (\%)} = \frac{W_{cai} - W_c}{W_{cd} - W_c} \times 100$$

(IS 13875-1993; Keulen and Young 1977; Dhimate 2014) where W_{cai}, W_c+acid insoluble ash (g).

Dust in bruised straw is mainly inorganic and organic. Dust concentration is the percent inert material present in the given bruised wheat straw sample. For determination of dust concentration in bruised wheat straw, a 20 g sample was taken and poured onto a sieve of 100 µm mesh size. The separation of dust by sieving was done manually for all the samples. Dust concentration was calculated as,

$$\text{Dust concentration (\%)} = \frac{Wd}{Ws} \times 100$$

where W_d, weight of dust (g); W_s, weight of straw sample (g).

The data obtained from the study was analysed statistically in factorial CRD using analysis of variance (ANOVA) and post hoc test at 5% level of significance using statistical software SAS 9.3.

Table 1 Independent and dependent parameters with their levels

Independent parameter	Levels	Nomenclature (value)	Dependent parameter
Sieve opening size (hole diameter, mm)	3	S1, S2 and S3 (3, 4 and 5)	Straw size Ash content
Sieve oscillations (strokes per minute)	3	O1, O2 and O3 (300, 350 and 400)	Acid insoluble ash Dust concentration
Straw load (kg)	2	L1 and L2 (0.572 and 0.738)	

RESULTS AND DISCUSSION

The developed system was evaluated in the laboratory for selection of best suitable combination of independent parameters.

Straw size: Mean straw size of bruised wheat straw increased with increase in sieve size (S) and sieve oscillation (O) but decreased with increase in straw load (L) (Table 2). The maximum straw size was observed for treatment S3O3L1 (25.63 mm) while, minimum value was observed for S1O1L2 (16.91 mm). The increase in straw size at increased sieve opening size and sieve oscillation could be attributed to better straw inter-particle motion, increased effect of sieving with increased sieve opening area and separation of fine straw particles. Also, with increased sieve opening size and sieve oscillations, the larger straw particles remained over the sieve at low straw load. The increase in straw size, at low straw load L1, with increase in sieve opening size and sieve oscillation could be attributed to increased momentum on the straw load. Larger sieve opening size (S3), higher sieve oscillations (O3) and low straw load L1 were also expected to remove small straw particles quickly than at high straw load L2. The same trend has been observed under straw load L2 at higher sieve size and sieve oscillation. The first order interaction between sieve size and sieve oscillation (S×O) was non-significant ($P>0.05$) whereas, sieve size and straw load (S×L) and sieve oscillation and straw load (O×L) was significant ($P<0.05$). The desired straw size ≤ 25 mm was observed in all treatment combinations except in S3O3L1. It is found that straw size

Table 2 Effect of sieve size (S), sieve oscillation (O) and straw load (L) on mean straw size (mm), ash content , acid insoluble ash and dust concentration.

Sieve size (S)	Mean for sieve size (S) × sieve oscillation (O) × straw load (L)					
	L1			L2		
	O1	O2	O3	O1	O2	O3
Straw size						
S1	19.33	20.10	20.60	16.91	18.21	19.89
S2	21.79	23.25	23.80	18.83	19.73	21.48
S3	22.66	24.82	25.63	20.09	21.90	23.21
Ash content						
S1	O1	O2	O3	O1	O2	O3
S2	11.71	10.02	9.46	15.30	13.31	11.52
S3	10.24	9.76	8.63	12.31	11.01	10.77
Acid insoluble ash						
S1	8.63	6.83	6.34	11.91	10.05	7.95
S2	6.88	6.54	5.81	7.79	7.62	7.25
S3	5.62	5.51	5.14	6.28	5.97	5.90
Dust concentration						
S1	O1	O2	O3	O1	O2	O3
S2	9.03	7.23	6.74	12.31	10.45	8.35
S3	7.28	6.94	6.21	8.19	8.02	7.65

at S3O2 and S3O3 was non-significant ($P<0.05$). Hence the desired straw size was observed at S3O3 for both straw load L1 and L2, respectively.

Ash content: It was observed that ash content of bruised wheat straw decreased with increase in sieve opening size and sieve oscillation. Whereas, it showed an increasing trend with increase in straw load (L) (Table 2). The reduction in ash content at increased sieve opening size and sieve oscillation could be attributed to better straw inter-particle motion and increased effect of sieving with increased inertia of the straw load as discussed in straw size. It was observed that mean ash content was minimum (8.60%) for sieve size S3 as compared to sieve size S2 (8.63%) and S1 (9.46%) at sieve oscillation O3 and straw load L1. This was because sieve size S3 has considerably larger hole area 19.63 mm^2 as compared to 12.56 mm^2 for sieve S2 and 7.06 mm^2 for sieve S1 at lower straw load L1. The higher perforation surface area in case sieve S3 effected the reduction in ash content. The larger sieve size opening area 19.63 mm^2 per hole is expected to remove more entrained soil associated with ash content of straw at higher oscillation and lower straw load than the smaller sieve opening area. Similar trend was observed for sieve size S3 and sieve oscillation O3 under straw load L2. The effect of sieve size (S), sieve oscillation (O) and straw load (L) were significant ($P<0.05$). The first order interaction between sieve size and sieve oscillation (S×O) and sieve size and straw load (S×L) was significant ($P<0.05$) whereas sieve oscillation and straw load (O×L) was non- significant ($P>0.05$). The highest mean ash content of 13.51% was observed in S1O1 interaction and lowest 8.68% was observed in S3O3 interaction. The mean ash content was not significantly different between the treatment combinations S3O3, S3O2, S3O1, S2O3 and S2O2. The highest mean ash content of 13.51% was observed in S1O1 interaction and lowest 8.68% was observed in S3O3 interaction. Thus, the best operational parameters for minimum ash content was observed at S3O3 for both straw load L1 and L2.

Acid insoluble ash: It was observed that acid insoluble ash content of bruised wheat straw decreased with increase in sieve size (S) and sieve oscillation(O). Whereas, it showed an increasing trend with increase in straw load (L) (Table 2). The minimum value was observed for the treatment S3O3L1 while maximum value was observed for the treatment S1O1L2. The reduction in acid insoluble ash at increased sieve size and sieve oscillation could be attributed to better straw inter-particle motion and increased effect of sieving with increased sieve opening area. Also, with increased sieve size and sieve oscillations the adhesion of dust particles with bruised straw was broken due to agitation which resulted in reduction of acid insoluble ash. The reduction in acid insoluble ash at low straw load L1 with increase in sieve size and sieve oscillation allowed quick separation of dust. Larger sieve size and low straw load is expected to remove more dirt associated with acid insoluble ash. The larger sieve size opening area 19.63 mm^2 per hole on sieve S3 is expected to sift more entrained soil associated with acid insoluble ash of bruised straw at higher oscillation O3 and lower straw load L1 than the smaller sieve opening area. The effect of sieve size (S), oscillation (O) and straw load

(L) were significant (P<0.05). Also, the first order interaction between sieve size and sieve oscillation (S×O) and sieve size and straw load (S×L) were significant (P<0.05) whereas, sieve oscillation and straw load (O×L) was non-significant (P>0.05). The combinations which were not significantly different under straw load L1 and oscillations (O) are L1O3 and L1O2; and L1O2 and L1O1, but at same straw load the combination of L1O3 and L1O1 was significantly (P<0.05) different. Similar trend was observed under straw load L2 in L2O3 and L2O1 respectively. However, mean acid insoluble ash at oscillation O1 and O3 were significantly different at straw load L1 and L2, respectively. Minimum acid insoluble ash was observed at operational parameters S3O3 for both the straw load L1 and L2, respectively and their difference in values were non-significant (P>0.05).

Dust Concentration: The maximum dust concentration was observed for treatment S1O1L2 while the minimum value was observed for the treatment S3O3L1. It was observed that dust concentration of bruised wheat straw decreased with increase in sieve size (S) and sieve oscillation(O) whereas, it increased trend with increase in straw load (L) (Table 2). The reduction in dust concentration at increased sieve opening size and sieve oscillation could be attributed to better straw inter-particle motion and increased effect of sieving with increased sieve opening area. Also, at increased sieve size and sieve oscillations, the adhesion of dust particles with bruised straw may have broken which resulted in reduction of dust concentration. The reduction in dust concentration at low straw load L1 with increase in sieve size and sieve oscillation allowed quick reduction in dust concentration. Sieve size (S), sieve oscillation (O) and straw load (L) had significant effect on dust concentration (P<0.05). The first order combinations of interaction between sieve size and sieve oscillation (S×O) and sieve size and straw load (S×L) were significant (P<0.05) whereas, sieve oscillation and straw load (O×L) was found to be non-significant (P>0.05). The combinations of interaction which were non-significantly different under straw load L1 and oscillations (O) were L1O3 and L1O2; and L1O2 and L1O1, but at straw load L1 the interactions of L1O3 and L1O1 was significantly different (P<0.05). Similar trend was observed under straw load L2 in L2O3 and L2O1 respectively. This was because there was not much difference between oscillation O2 with O3 and O2 with O1 under load L1 and similarly under load L2. However, mean dust concentration at oscillation O1 and O3 were significantly different at straw load L1 and L2, respectively. Minimum dust concentration was observed at operational parameter S3O3 for both straw load L1 and L2 respectively, and difference in value is non-significant (P>0.05).

The results obtained from optimisation of operational parameters for dust separation system of wheat straw combine using sieve setup under laboratory evaluation indicated that independent parameters significantly affected ash content, acid insoluble ash and dust concentration.The operational parameter, sieve opening size ϕ 5 mm and sieve oscillations 400 spm resulted in better straw quality parameters such as ash content, acid insoluble ash and dust concentration in the range of 8.60–8.77%, 5.14–5.90% and 5.44–6.30%, respectively. These operational parameters (sieve opening size ϕ 5 mm and sieve oscillations 400 spm are selected for development of integral dust separation system on wheat straw combine for field testing and evaluation.

ACKNOWLEDGEMENT

The authors acknowledge the financial assistance provided under AICRP on FIM by ICAR and Punjab Agricultural University, Ludhiana for providing facilities to carry out this research.

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