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Performance assessment and optimization of maize dehusker cum sheller - A technology for Northern Transition Zone of Karnataka

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ABSTRACT

Maize (*Zea mays* L.) is one of the major crops in Karnataka state grown for commercial and seed-production purpose. In Northern Transition Zone (Hyderabad-Karnataka region), the major farming sizes of land are limited small to medium holding and they were in the need of economical technique for maize dehusking and shelling operation suited to medium capacity. In present study, the medium sized electric motor (2.23 kW) operated maize dehusker cum sheller (MDS) was developed and evaluated for selected operational parameters, viz. cylinder peripheral speed (6.2, 6.6, 7.1 and 7.6 m/s), concave clearance (20, 25, 30 and 35 mm) and feed rate (400, 600 and 800 kg/h). The machine performance parameters revels that, the dehusking efficiency and shelling efficiency were showed increasing trend with cylinder peripheral speed (S) from 6.2 to 7.6 m/s; whereas decreasing trend against increase in Concave Clearance (C) from 20 mm to 35 mm. The total losses of grains in machine were found lowest between feasible at 25 to 30 mm of C for all feed rates (F). In seed-quality parameters, the decreased germination percentage with increase in S was observed. The increased broken grains (%) and seed-coat damage (%) were identified with increased in S and decrease in C as well as F. The highest desirability value (obtained from numerical optimization technique) was obtained for operational parameter combination of S at 7.1 m/s with C at 25 mm under 600 kg/h of F. The total cost of the MDS was ₹ 34500 with benefit-cost ratio of 2.24. The performance of machine was also satisfactory for producing maize seeds for seeding purpose without compromising its performance.

Key words: Dehusker sheller economics, Maize dehusking shelling, Maize sheller evaluation

In developing countries like India, the agricultural productions system is the main source of livelihood for one third of population. The farmers' dependency for food and fodder supplementing with main crops of cultivation rather than selling commercial crop produce for capital generation (Chaudhary *et al*. 2012). As per study of Directorate of Maize Research, livestock production is contributing 7% to National GDP and a source of employment and ultimate livelihood for 70% of the population in rural areas. In addition, the climate change presents a major risk to long term food security as it may decline wheat and maize yields by 5 to 10 % by 2050 (Anonymous 2016). Maize ranks third in production (24.17 mt) and fifth in area (9.06 m-ha) during 2013-14. In India, maize is grown in all the seasons (Anonymous 2013), where Karnataka state is the second largest maize producing (4.1 mt) state contributing to 17% of total country production (24.17 mt) after Andhra Pradesh (Anonymous 2016c). In farming, mechanization in harvesting and threshing is below 20% (Singh 2010). Traditionally, dehusking and shelling of maize are carried out by manually which involves a lot of drudgery (Mudgal *et al*. 1998, Singh 2010, Naveenkumar 2011, Anonymous 2012). The output of manual separation reported to be 30 kg/h with shelling efficiency of 80-100% and grain damage of 0 to 8.3% (Mudgal *et al.* 1998, Anonymous 2005, Chilur *et al*. 2014). The capacity of manually operated shellers (27 to 150 kg/h) is apt for marginal farmers, whereas engine operated (1000 to 1800 kg/h) and tractor operated (>2000 kg/h) maize shellers are apt for large farmers and no machines were developed with 200 to 1000 kg/h capacity for seeds production suitable for small and medium farmers (Singh *et al*. 2011). In present study, to fulfil the demand of small to medium sized farms, the MDS was developed, since 80.3% of farmers are marginal and small group cultivating 36% of the area (Naveenkumar 2011) in the country. Hence, the objective has been taken for developing MDS with no compromise in its performance to reach the existing maize dehusking cum/and shelling machineries (Sarma 2007, Singh and Singh 2010, Singh *et al*. 2011, Vyavahare and Kallurkar 2015) with minimum damage to maize seeds, with the aim of using for seeding purpose.

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MATERIALS AND METHODS

The engineering properties (viz. physical, aero-dynamical and frictional) of most commonly growing four maize varieties (viz. Mahyco (Hero 550), Hema hybrid variety, Ganga Kaveri (GK-3090) and CP818) were studied (Chilur and Sushilendra 2016) and considered in design of MDS (Mohsenin 1970, Jayan and Kumar 2004, El-Fawal *et al*. 2009, Coskun *et al*. 2006). For the developed MDS laboratory and on-farm testing were carried out (with CP 818 maize variety) in CAE, Raichur (16.205057° N, 77.329972° E) and Agricultural Research Station, Siraguppa (15.630577° N, 76.916559° E), respectively.

Principle of machine working: The axial flow of undehusked maize-cobs flows through clearance zone between cylinder and sieve (concave clearance (C)) due to the helical-pathed squared cum chamfered-lugs rotation (cylinder peripheral speed (S)) on cylinder drum. The cobs bear several movements leads to tearing and abrasion of cobs, which causes the detachment of sheath and grains from cob (Anonymous 2004, Danfulani 2009, Gole and Shahu 2009).

The main processer of MDS, i.e. threshing cylinder was designed and selected as 1000 mm length by considering standard acceptable permissible feed rate of 0.0216 kg/s/m and eight beater lines were chosen to makes 44 lugs (Hassan *et al*. 2009, Tarighi *et al*. 2011). The diameter of cylinder including lugs height (42 mm) was kept as 250 mm (opted based on undehusked cob diameter and cob length) to achieve the selected range of peripheral tip speed of cylinder. Concave was made of mild steel (MS) material to sustain and reinforcement to increase the strength and at the bottom, a 12 mm holed sieve was used based on maximum arithmetic diameter of grain. The 'throw-in' hopper and curved square opening was provided as an outlet for dehusked and shelled cobs and husk (called as cob outlet). The two-half circular shaped MS sheet below the concave at 35° (called as grain collecting unit) along cylinder axis was provided for collecting grains from either side of cylinder to centre (cleaning unit) after dehusking and shelling. The grain collecting unit conveys grain and material other than grain (MOG) to cleaning unit, *i.e*. other open-rectangular inclined (35°) unit, which was placed below and across the cylinder axis against the air stream of blower. The line diagram of the MDS in isometric view is shown in Fig 1. The overall dimensions (length × width × height) of developed MDS machine were 1200 × 610 × 810 mm.

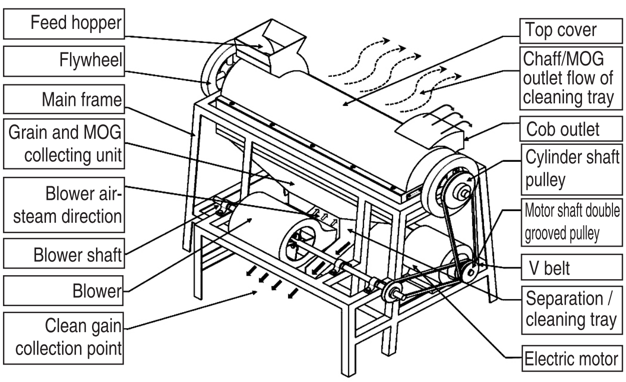

Fig 1 Detailed view of developed maize dehusker cum sheller

It is evident from the literature that, power requirement increases with the increase in the Feed Rate (F) and Cylinder Peripheral Speed (S) (Olaoye 2002, Tastra 2009, Sachin 2008 , Tiwari *et. al*. 2010). Since, the design of MDS was carried out suitable (for marginal, small and medium farmers) for the F of 400 to 800 kg/h, based on initial trails power consumption (up to 1160 W) test, the three phase 2.23 kW, 950 rated rpm electric motor was selected as prime mover. The properties study showed that terminal velocity of the husk and grains were 1.2 m/s and 15.12 m/s respectively and therefore, actual air flow rate required was found to be 0.062 m^3/s for achieving 1.77 m/s air stream over cleaning tray (Klenin *et al*. 1985, Bosoi *et al*. 1990) from desired size of developed blower unit.

Performance evaluation of developed MDS was carriedout in accordance with procedure and guidelines prescribed by the Indian Standard Test Code IS: 7051-1973 and IS: 6284-1985 for cereals. In pre-test observations, the moisture content and grain to straw ratio were observed as 11.25% and 3.95, respectively. A three-phase wattmeter was used to test at no-load to know the idle power consumption of MDS. The idle power consumption was found as 455 W, out of that 42.85% was consumed by motor, whereas 24.31% by threshing cylinder, 15.16% by blower and 17.68% consumed by miscellaneous. During the test at load, the machine was evaluated at different parameters as shown in Table 1.

As per Indian Standard (IS 1985, IS 1973) each trial with 25 kg sample feed was done and output samples were collected for 60 seconds form all outlets separately. The Total Grain Input Per Unit Time (Gin) were calculated by summing clean grains, broken grains and unthreshed grains collected over per unit time from all outlets. The Dehusking Efficiency (DE) was found by ratio of number of dehusked cobs to the total number of cobs used. Similarly, Shelling Efficiency (SE) is the alternative to fraction of unthreshed grain [i.e. 100 – (% of Unthreshed grains)]. The unthreshed grain percentage is the ratio of unthreshed grains per unit time from all outlets to G_{in}. Total losses (L_t) is the sum of the percentage of broken grains, unthreshed grains and blower loss; where, broken grain percentage (D_b) is the ratio of the quantity of broken grain from all outlets per unit time to the Gin and blower loss is the fraction of summed amount of sound (whole or unbroken) and broken grains come out at chaff outlet of cleaning tray (Fig 1) to G_{in} (Akubuo 2002). The wattmeter used to determine the power consumption at idle and load condition of MDS for particular F to determine the input capacity (kg/kW-h). The Input Capacity (Ci) is calculated by relation (Eq. 1) shown below.

$$C_i = \frac{\text{Amount of material fed, kg}}{\text{Time taken for feeding, h} \times \text{Average wattmeter reading, kW}} \qquad \text{(Eq. 1)}$$

Germination percentage of seeds (G) was determined by the paper towel method as prescribed by International Rules for Seed Testing. The total germination counts (on the fourth and seventh day for I and II counts) were made

Table 1 The operational and response parameters studied for developed MDS at test at load

Independent/Operational parameters				Response variables	
	Levels	Description	Value	Machine-performance	Seed-quality
Cylinder peripheral speed (S), m/s	4	S_1	6.2	Dehusking efficiency (DE), %	Broken grain losses (D_b), %
		S_2	6.6		
		S_3	7.1		
		S_4	7.6	Shelling efficiency (SE), %	
Concave clearance (C), mm	4	C_1	20		Germination (G), %
		C_2	25		
		C_3	30	Total losses (L_t), %	
		C_4	35		
Feed rate (F), kg/h	3	F_1	400	Input capacity (C_i), kg per kW-h	Seed-coat damage (D_c), %
		F_2	600		
		F_3	800		

Note: The asymmetric factorial experiment with completely randomized design was used for statistical analysis with Design Expert package licenced to UAS, Raichur.

on normal healthy seedlings from a sample of fifty seeds in three replications and germination percentage was calculated by the ratio of number of grains were germinated at the end of II count to total number of seeds used in test (Ghaly 1985, ISTA 2013).

For safe storage of seeds and proper germination, the protection of embryo is important by intact seed-coat. Therefore seed-coat damage was identified by standard ferric chloride test (Copeland and McDonald 1985). In this method, 20% of ferric chloride solution (20 g of $FeCl_3$ in 100 ml distilled water) was prepared in 250 ml beaker and 100 seeds were soaked for 15 min in beaker. The seeds were observed by electronic microscope and images were acquired using Leica Application Suit (Version 2.1.0 (Build 97). The brown/dark coloured crack lines/patches over seed-coat were identified as mechanically damaged (Since, they can't be used as seeding purpose and not capable for longer storage) and the fraction of coloured to total seeds used in test were represented as Seed-coat Damage Percentage (Dc).

To study the effect of different operational parameters on performance parameters, a 4 × 4 × 3 asymmetric factorial completely randomized design was considered (Table 1). For optimization, the set of constraints (maximization, minimization and in-the-range) were applied to various independent (S, C and F) and dependant/performance parameters (DE, SE, Lt, Db, Ci, G and Dc) in numerical optimization technology to optimize the treatments. Further, highest desirability valued treatment combination was chosen as optimal. To verify the MDS performance with chosen factors, the experiment was re-conducted and obtained actual values compared with predicted values (by Design Expert (Version 7.0.0) package, licenced to UAS, Raichur) and variation were noticed (Montgomery 2001).

The cost involved in raw material, fabrication, labours, etc. were considered to the cost of MDS and annual cost of operation (fixed+variable cost) was also calculated by considering eight-year life time (Ojha and Michael 2009). The fixed cost includes depreciation, interest on investment, annual intrust (15%), taxes (2%) and housing (1%). The operating cost includes the cost of repairs and maintenance (8%), electricity charge and labour wages for running. The payback period calculated by fractionating initial investment to net annual return (₹/year). The benefit cost ratio was calculated by using the following formula (Reddy and Devi 2003).

$$\text{Benefit-Cost ratio} = \frac{\text{Discounted return}}{\text{Discounted cost}} \tag{2}$$

$$\text{Discounted return} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^2} \text{ and Discounted cost} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^1}$$

where, B_t = Returns for year t, rupees; C_t = Cost for 8th year (Considering yearly 2% increasing in cost of operation), rupees; t = Economical life (8 years); r = Discount rate (12%), fraction.

RESULTS AND DISCUSSION

Machine performance evaluation

The effect of cylinder peripheral speed (S) and concave clearance (C) on dehusking efficiency (DE) of MDS is presented in Figs 2a, 2b and 2c, which have mean DE of 95.40%, 94.89% and 94.01% with respect to F1, F2 and F3 feed rate (F), respectively. The trend shows that DE decreased with increase in C for all the S tested because of increase in C makes less dense cobs inside leading to less abrasion and further cob moves towards outlet in shorter time causing the decreased dehusking action. The similar findings were reported by Singh (2010). The increasing trend of DE rate was observed up to S of 7.1 m/s thereafter it was nearly same until 7.6 m/s. The DE was maximum at C of 20 mm, while it was minimum for C of 35 mm for all the S. On other hand, all individual factors affected each other significantly whereas, all other interaction effects were non-significant other than S&C (Table 2). The results were analogous to findings of Vas and Harrison (1969) and Singh (2010).

From Figs 2d, 2e and 2f, the data revels that, the shelling efficiency (SE) varied from 91.02% to 99.68%. An increased F resulted in the decreased SE due to less energy spent per cob in terms of less number of impacts taken place on cobs for same length of cylinder. On other hand, the 'cushioning' effect at higher feed rates caused to decrease in SE. Further, the increased S resulted higher SE due to the increased detachment with higher impacts and friction created between the cylinder and concave. After S of 7.1 m/s, increase in SE rate was less due to less retention time of cobs in concave and it might have increasing conveyance of plant mass by angled (45°) lugs arrangement. The results showed that C1 and C2 concave clearances gave higher SE, further it decreased with the increase in C. The C had significant effect on the shelling efficiency (Table 2). The maximum shelling efficiency was obtained at F1 and F2 feed rates for S3 and S4 cylinder peripheral speeds and C1

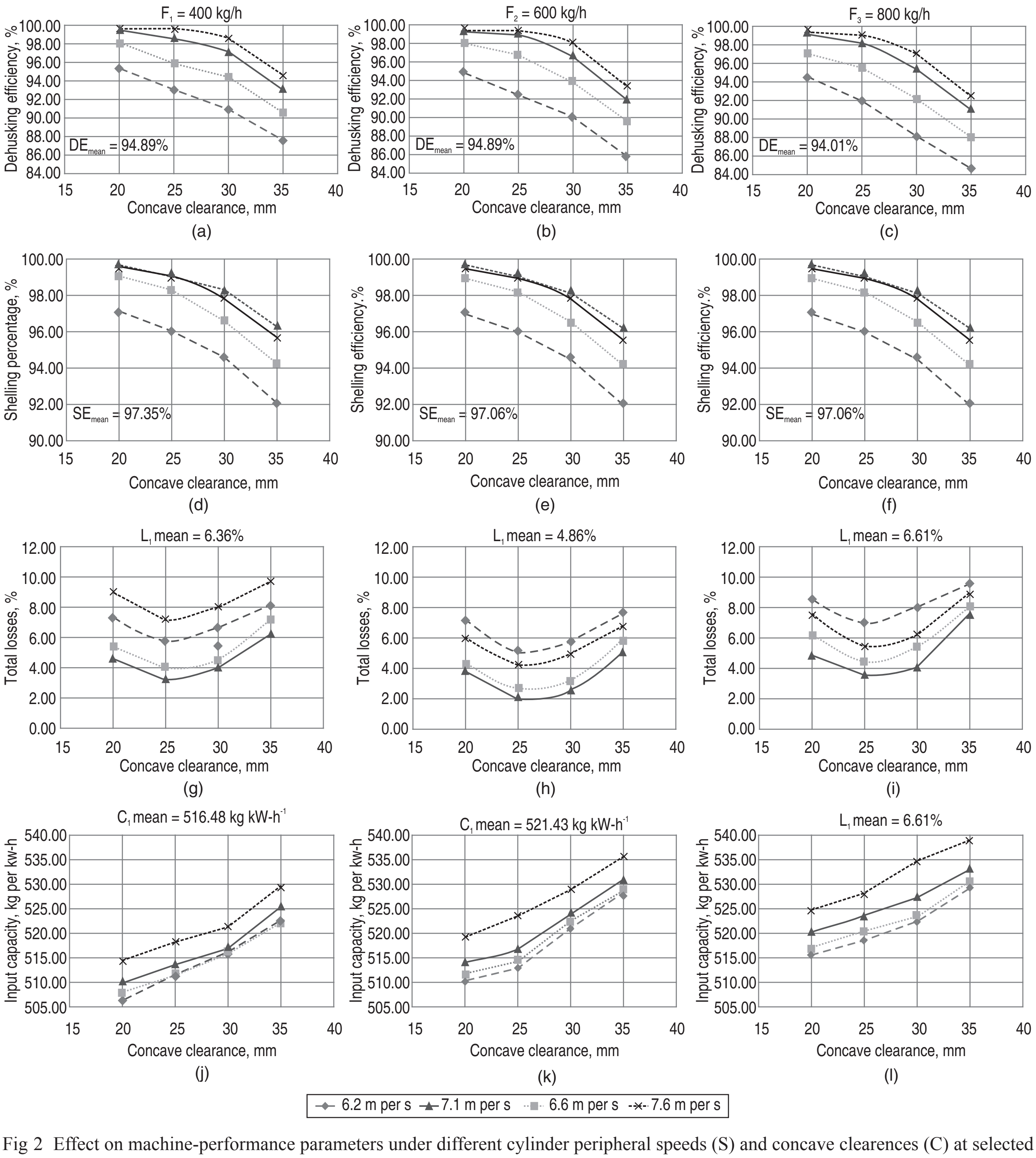

Fig 2 Effect on machine-performance parameters under different cylinder peripheral speeds (S) and concave clearences (C) at selected feed rates (F) of developed MDS

Table 2 ANOVA for machine-performance parameters at different feed rate (F) for various cylinder peripheral speed (S) and concave clearance (C)

Source	DOF	Sum of squares				F value			
		DE	SE	L_t	C_i	DE	SE	L_t	C_i
S	3	1112.29	404.09	207.65	2393.63	238.52*	337.90*	171.35*	49.97*
C	3	1200.60	242.04	139.46	3128.55	257.46*	202.39*	115.08*	65.31*
F	2	129.87	46.38	33.53	832.65	41.78*	58.17*	41.50*	26.07*
SC	9	79.04	27.87	12.40	657.01	5.65*	7.77*	3.41**	4.57*
SF	6	27.80	6.70	8.06	36.75	2.98**	2.80**	3.32**	0.38**
CF	6	17.97	8.09	8.43	214.35	1.93**	3.38**	3.48**	2.24**
SCF	18	27.53	33.21	36.13	2633.91	0.98**	4.63*	4.97*	9.16*
Pure error	96	149.22	38.27	38.78	1532.97	-	-	-	-
Total	143	2744.31	806.64	484.43	11429.8	-	-	-	-

DOF: Degree of freedom; DE: Dehusking efficiency; SE: Shelling efficiency; L_t: Total losses; C_i: Capacity of input/kW-h; '*' and '**' = Significant and non-significant at P≤0.05, and 0.01, respectively. CD value of interaction factors viz. SC, SF, CF and SCF for DE parameter were 0.8, 0.9, 0.64 and 1.13 at 1% level of significance.

and C2 concave clearances.

Total loss depends on the many parameters, viz. total broken, unthreshed grains and blower loss. From Figs 2g, 2h and 2i, the data shows percentage of total loss (L_t) varied from 2.12% to 9.70%. As the C increased from 20 to 25 mm, the L_t decreased. Thereafter it increased up to 35 mm for all the S and F. This may be due to the decreased broken grains, unthreshed grains and blower loss at higher F and simultaneously increasing trend of losses as S increases (Sandhar and Panwar 1975). Among all F,

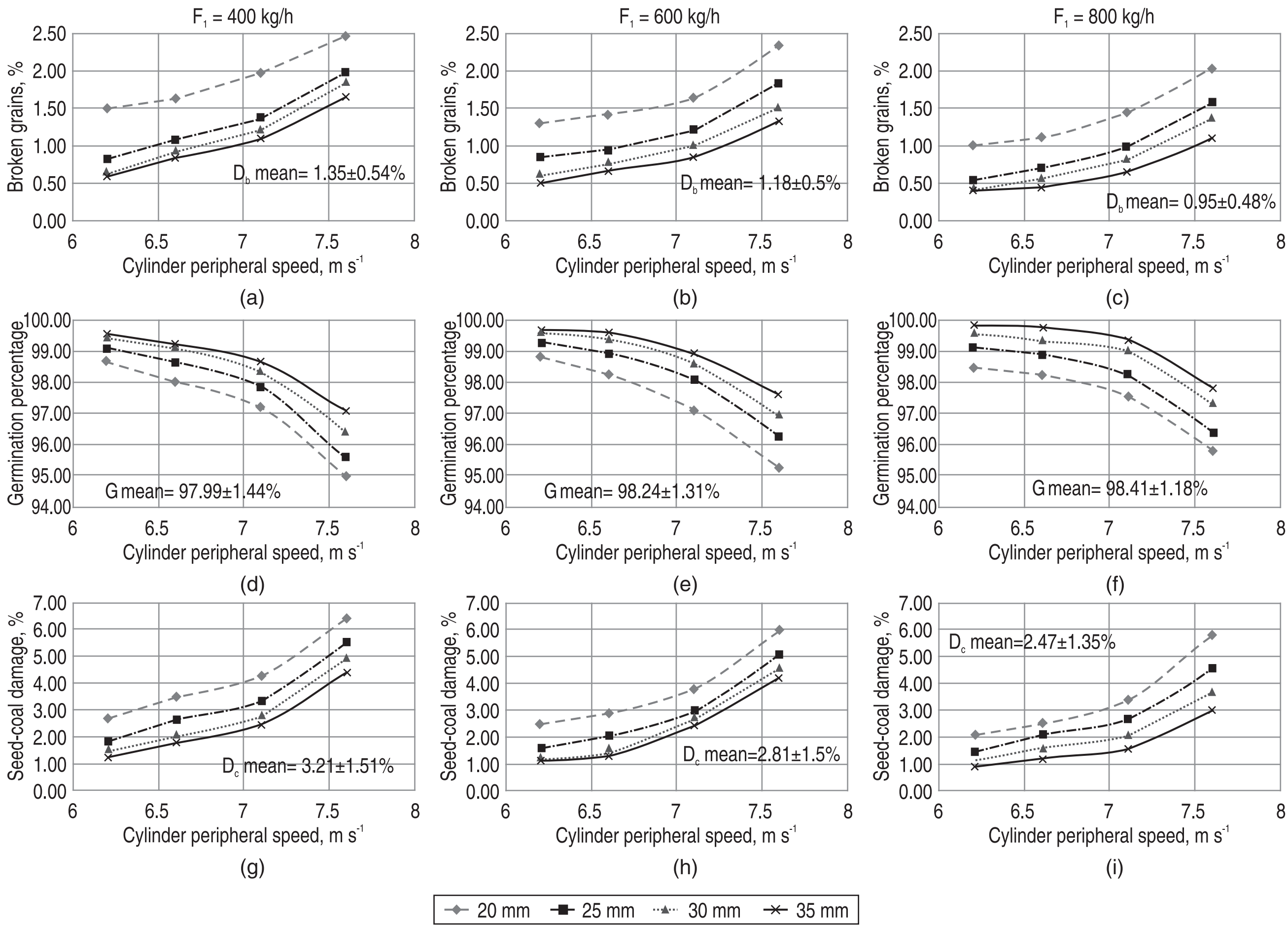

Fig 3 Effect on seed-quality parameters under different cylinder peripheral speeds(S) and concave clearances(C) at selected feed rates(F) of developed MDS

Table 3 ANOVA for seed-quality parameters at different feed rate (F) for various cylinder peripheral speed (S) and concave clearance (C)

Source	DOF	Sum of squares			F value		
		D_b	G	D_c	D_b	G	D_c
S	3	23.79	194.90	234.72	446.80*	284.62*	333.46*
C	3	9.85	32.88	32.73	185.05*	48.01*	46.50*
F	2	2.47	8.08	8.22	69.55*	17.70*	17.53*
SC	9	1.49	5.97	6.10	9.30*	2.90**	2.89**
SF	6	0.11	1.62	1.67	1.00**	1.18**	1.19**
CF	6	0.36	1.02	1.10	3.34**	0.75**	0.78**
SCF	18	0.53	15.58	15.77	1.66**	3.79*	3.73*
Pure error	96	1.70	21.91	22.52			
Total	143	40.30	281.95	322.84			

DOF: Degree of freedom; D_b: Broken grain percentage; G: Germination percentage; D_c: Seed-coat damage percentage. '*' and '**' = Significant and non-significant at P≤0.05 and 0.01, respectively. CD value of interaction factors *viz.* SC, SF, CF and SCF for D_b parameter were 0.09, 0.07, 0.07 and 0.12 at 1% level of significance.

the minimum L_t was at F_2 feed rate and it was significantly higher at F3 feed rate but on par with F1.

The mean input capacity (kg/kW-h) for all C, increased with F and S in MDS (Fig 2j, 2k and 2l). The results agree with the findings of Ghaly (1985). The lowest C_i was obtained for 6.2 m/s with respect to 20 mm of C at a feed rate of 400 kg/h.

Seed-quality parameters evaluation

From the Fig 3a, 3b and 3c it was found that mean percentage of broken grains (Db) at F1, F2 and F3 feed rates were 1.35±1.54%, 1.18±1.5% and 0.95±1.35%, respectively. An increased F resulted in decreased D_b for all the S and C. Overly, increased C resulted in decreased trend of D_b for all S and F. As C increases, the impact by cylinder lugs on less number of grains in one revolution of the cylinder may be attributed as the reason for decreased D_b (Akubuo 2002). In other hand, boosting the S leads to enhances in D_b, due to higher severity of rubbing action of cobs. Since, they impart higher energy with speed. The above findings revel that, the D_b trend reduced by increasing F&C and decreasing S. Also, it was observed that the effect of S and C factors on the grain broken percentage was slightly higher than F factor.

Since, the maize seeds higher in germination percentage (G) as compare to other cereals (Anonymous 2016b), it was observed in study that, *i.e.* varied from 94.97 to 99.98% in all treatments (Fig 3d, 3e and 3f). The G was maximum (99.82%) in F3C4S4 and lowest (94.97%) in F1C1S4 treatment. At the F of 400 kg/h, it was in the range of 94.97 to 99.55% whereas it was 95.22 to 99.65% and 95.82 to 99.82% for 600 and 800 kg/h, respectively. The increasing S had significant effect on decreasing the G, whereas it's having reverse effect from C. The result shows that higher percentage range of non-germinated seeds as compare to range percentage of broken, which means some of the non-broken seeds also not get germinated may be due to mechanical damage of embryo, seed-coat, etc. So, lesser the S and higher the C and F might have recommended for achieving the more G for seeds processed in developed MDS.

The Seed-coat Damage Percentage (Dc) of maize seeds was highest at (6.38%) higher S, lowest C and lowest F, while minimum (0.89%) recorded in slower S, at higher C and higher F. Its trend was similar to broken grains percentage and opposite to germination percentage of seeds (Fig 3g, 3h and 3i). The mechanical damage of maize was observed in the range of 6.38 to 16% by Chowdhury and Buchele (1976) and Singh *et al*. (2011) for conventional combines whereas, in the present study it is less (0.89 to 6.38%) due to lower operating speed and prototype designed for only maize shelling and dehusking for seed production. The lesser damage in developed MDS may be due to the use of chamfered squared cornered lugs on the cylinder and the helical arrangement which not support to augment of Dc. The Dc was higher than that of the percentage of non-germinated seeds, which shows that some of the cracked seeds were not germinated due to more severe seed-coat damage or may be the embryo part gets damaged (Ghaly 1985). The effect range from different factors on Dc can be observed in order of S>C>F. Further, the first level factors and interaction of SCF was significant at 1% and 5% level of significance (Table 4). The reviews' data of Handbook was recommended the S of 9 m/s for husking of maize cobs. Since present problem to produce maize grains for seeding purpose, the lower speed, *i.e.* below 7.1 m/s was found in agreement with concern to seed-quality aspects.

Optimization of operational parameters of MDS

The solutions were found within all the treatment combinations with a highest desirability up to 0.759 at 7.1 m/s of S, 25 mm of C and 600 kg/h of F. The re-experimented results of machine at optimal found treatment combination (S=7.1m/s, C=25mm, F=600kg/h) shows acceptable variation (0.19 to 2.89%) between initial and re-experiment results.

The total production cost of MDS was ₹ 34,500. The dehusking and shelling hiring price were ₹ 5/qt based on machine feed rate of 600 kg/h with 250 annual working hours (8-year life time) and considering annual cost of operation (Fixed + running = ₹ 7762.5 + ₹ 12 118.7). The payback period (Investment/net annual return = ₹ 34500/₹ 46064) was found to be 0.74 year. The benefit cost ratio (Discounted return/ discounted cost = ₹ 441,597/₹ 196512) was found to be 2.24. This developed machine is six-time lower operating cost (₹ 5/qt) than pedal operated tubular maize sheller (Capacity: 70-72 kg/h, cost: ₹ 33.51/qt) (Chilur *et al*. 2014), twelve times lesser than CIAE octagonal hand held tubular maize sheller (Capacity: 20 kg/h, cost: ₹ 68.3/qt) and twenty times lower than manual shelling (Capacity: 10-12 kg/h, cost: ₹ 115.7/qt) (Anonymous 2016a).

The developed maize MDS for producing quality seeds was satisfied for desired capacity to suit small to medium farmers in Northern Transition Zone of Karnataka as per objectives for producing good quality grains for seeding purpose, the special care need to be taken in design of dehusking-shelling cylinder. In this case, the parallel-staggered-parallel lug arrangement with chamfered corners were found satisfactory. Dehusking efficiency, shelling efficiency decreases as increase in concave clearance and increases with cylinder peripheral speed. The total losses were found to be feasible at 25 to 30 mm of C with S of 6.6 to 7.1 m/s for any feed rate. The input capacity increases with cylinder peripheral speed, concave clearance and feed rate. The broken grains and seed-coat damage decreased with decreasing cylinder peripheral speed and increased with concave clearance, and feed rate were inferred from study. The optimum operating conditions of cylinder peripheral speed, concave clearance, and feed rate were 7.1 m/s, 25 mm, and 600 kg/h, respectively. The initial cost of the MDS was ₹ 34500 and the annual cost of operation was recorded as ₹ 12118 with payback period of 0.74 year (with life time of 8 years). The benefit cost ratio was 2.24.

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