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SPEED OPTIMIZATION USING VARIABLE FREQUENCY DRIVE FITTED TO DHAN FOUNDATION DEHULLER

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Abstract– Speed optimization using variable frequency drive fitted to dhan foundation dehuller were done to know the effective dehulling speed with time of dehulling in selected minor millets. The selected minor millets included proso millet, kodo millet, little millet, foxtail millet and barnyard millet. The selected speeds were 21,28 and 35Hz. Dhan foundation dehuller has an input hopper, dehulling impeller type mechanism and an outlet for dehusked grain and an aspirator for removing the lighter weight hull that it is to be separated. 1kg of raw millet of different types were taken for dehulling experiments. Head rice recovery after dehulling is lowest for kodo millet, 8.15%±5.62 followed by barnyard millet, 26.07%±11.24, foxtail millet, 46.04%±16.90, proso millet, 53.19%±14.46 and little millet,53.73%±11.93. Broken rice recovery ranged between 7.59 to 12.3%±1.39 for proso millet, for kodo millet, it is 5.72 to 16.49%±3.31, for little millet it ranged between 11.92 to 23.10%±3.30, for foxtail millet it is 8.88 to 20.72% ± 3.73 and for barnyard millet it is 17.35 to 35.62%±5.73. Performance index varied between 24.41 to 63.27±11.26 for proso millet, 0.75 to 18.25±5.33, in kodo millet, 18.60 to 70.73±13.27, for little millet, 12.75 to 64.85±15.62, for foxtail millet and 5.41 to 38.54±7.64 in barnyard millet. Capacity of satake polisher in polishing proso millet is 55.80 to 66.39kg/h±3.36, in kodo millet it ranges between 66.96 to 71.68kg/h±1.38, in little millet, it ranges between 44.15 to 63.7 kg/h±6.49, in foxtail millet it ranges between 58.71 to 66.22kg/h±2.17 and in barnyard millet, it ranges between 56.32 to 69.04kg/h±3.68 from 21Hz to 35Hz speeds. At 21Hz speed, the capacity is more in proso millet, 72.43kg/h±4.78 followed by kodo millet, 66.96kg/h±4.78, barnyard millet, 61.97kg/h±4.78, foxtail millet, 58.71kg/h±4.78 and little millet, 44.15kg/h±4.78. At 28Hz the capacity is more in kodo millet, 69.95kg/h±1.57 followed by barnyard millet, 69.04 kg/h ± 1.57, foxtail millet,66.22kg/h±1.57,little millet, 63.52 kg/h±1.57 and proso millet, 61.72kg/h ± 1.57. At 35Hz the capacity is more in kodo millet, 71.68 kg/h±2.45 followed by little millet, 63.7 kg/h±2.45, proso millet, 63.21kg/h±2.45, foxtail millet, 62.49kg/h±2.45 and barnyard millet, 56.32kg/h±2.45. The values of all the experiments are as a result of 2 replications. The values obtained were significant at 5% level of significance (p≤0.05) and found out using SPSS 16.0 version.

INTRODUCTION

Millets are known for their nutritional significance and they also have nutraceutical importance in curing diseases like diabetes and migraine due to their low digestable nature. Millets are rich in total dietary fibre and is an important diet of diabetes patients. But owing to their fibrous nature indigestion problem may occur and hence the outer hull that is of fibrous nature has to be removed for making value added products. Removal of the hull (dehulling) facilitates reduction of fibre and tannin content (Deshpande *et al.*, 1982), improvement in the appea -rance, texture and cooking quality (Kon *et al.*, 1973) palatability and digestability of the grain. Minor millets are very difficult to dehull because of their small size. Many dehullers are used for dehulling and one such is dhan foundation dehuller.

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Many dehullers are sturdy in their appearance and hence require more power to operate and this is a constraint for research and development purposes. To test the machine for its energy economic operation and its suitability for dehulling all type of millets, a dhan foundation dehuller is a must and this dhan foundation dehuller is developed. The unhulled millet grains are procured from the gubba storage godown and cleaned in a cleaner cum grader cum aspirator. 10kg of raw unhulled millet grain is dehulled using this type of dehuller for getting improved head rice recovery with less amount of brokens. Speed optimization is very much required to get higher head rice recovery in dehulling of millets. This speed optimization may be obtained by testing with variable frequency drive (vfd) at different speeds. Speed optimization using variable frequency drive fitted to dhan foundation dehuller were done to know the effective dehulling at varied speed with different time of dehulling in selected minor millets. Small millets are grown by farmers in the field and many farmers are below poverty line and depend on government's subsidy rate for electricity and the power consumption has to be reduced to make this millet crop processing a profitable venture. Hence this study becomes important in this context. This paper describes the conservation of power for efficient dehulling of minor millets. The main target is to reduce the electric energy consumption for dehulling of millets. In the present time, energy consumption is to such an extent that if the same trend goes on then in future at some point of time, the energy sources will be exploited. Thus, saving of energy even in small units is not only advantageous for the future but also benefits manufacturer as well as to the customers.

MATERIALS AND METHODS

The selected minor millets including proso millet, kodo millet, little millet, foxtail millet and barnyard millet were tested for its dehulling capability in the dhan foundation dehuller. The freshly harvested minor millet grains were procured and stored in the gubba storage. The minor millet grains were obtained from gubba storage for conducting experiments. 10kg lot of millet grains were subjected to cleaning cum grading cum aspirating in a cleaner cum grader cum aspirator. Then these grains were tested for its moisture content in hot air oven for its moisture content at 105°c until constant weight is reached. (AOAC,1984). These grains were stored in gunny bags for conducting experimental trials. Dhan foundation dehuller is used to dehull the different types of millets and variable frequency drive is used to determine the dehulling of minor millets at different selected speeds. The values of all the experiments are as a result of 2 replications. The values obtained were significant at 5% level of significance ($p \leq 0.05$) and found out using SPSS 16.0 version. A VFD regulate the voltage and frequency that a power supply delivers to a connected motor. A Variable Frequency Device is a device that controls the motor by varying its frequency and the voltage. Frequency is directly proportional to the revolution per minutes (RPM) of the motor, i.e. higher the frequency, higher is the speed of the motor and vice-versa. VFD, by varying the frequency and the voltage and thus, lowers the speed of the motor. At the same time, when the speed needs to be increased, VFD increases the frequency and the voltage. A drastic variation in power consumption can be found by employing a VFD in a hydraulic circuit as it saves a lot of energy when motor is not required to run at full speed. (Ramesh *et al.,* 2018). The separation is achieved by a cleaner cum aspirator after dehulling of minor millets. Proper labeling was done to make accurate calculations of the unhulled, dehulled and brokens millet grains. Measurements were made for sampling in an electronic balance.

RESULTS AND DISCUSSION

The moisture content is the most important parameter that influences the dehulling characteristic of the grain. Moisture has a significant effect on dehulling. The moisture content of the unhulled and dehulled millets was determined using infrared moisture meter. The moisture content of unhulled major and minor millets ranged between 4.61 to 7.68%wb±0.35, in major millets, ranged between 7.16 to 7.68%wb±0.35 and in minor millets, it ranged between 4.61 to 7.38%wb±0.35.The average unhulled millet moisture content is 6.73% wb±0.35. The moisture content of the dehulled millets ranged between 8.14 to 10.06%wb±0.64, the average moisture content is 8.98±0.64%wb. The major millets mc ranged between 7.84 to 9.82±0.64%wb and in minor millets mc ranged between 5.99 to 10.06%wb±0.64 (Fig. 1). The dehulling efficiency of un -hulled millets for the safe storage moisture content was determined. The moisture content also is an important parameter for dehulling of millets (Timothy *et al.*, 2019). Lesser the moisture more is the breakage. (Douglas Doehlert and Michael McMullen, 2001)

$$Mc(\%wb)= ((IW-FW)/FW)$$

IW-Initial weight, g

FW-Final weight, g

Milling is defined as processing of millets into edible form by removing and separating the inedible and undesirable portions from them without changing their shape (Amalendu Chakra - verty, 2020). The dhan foundation dehuller had a hopper, one crushing chamber, a blower for supplying air in a continuous manner with the provision for controlling the air flow rate. (Fig. 5) The hulling mechanism is by shear and compression in millets dehuller. The air flow rate is set according to the terminal velocity of the selected millet grains. The input of grain to the hopper can be adjusted so that dehulling takes place. The dehulled grain gets collected in the outlet chute. Variable frequency drive has the following advantages of large energy savings at lower speed, increased life of rotating components due to lower operating speed, reduced noise and vibration level and reduction of thermal and mechanical stresses and lower kva and high power factor (Tamal Aditya, 2013). Dehulling is measured as the percentage of the original weight that was dehulled. A large abrasive force is applied to obtain complete dehusking of the grains that causes high losses in the form of brokens and powder. The extent of milling is measured by

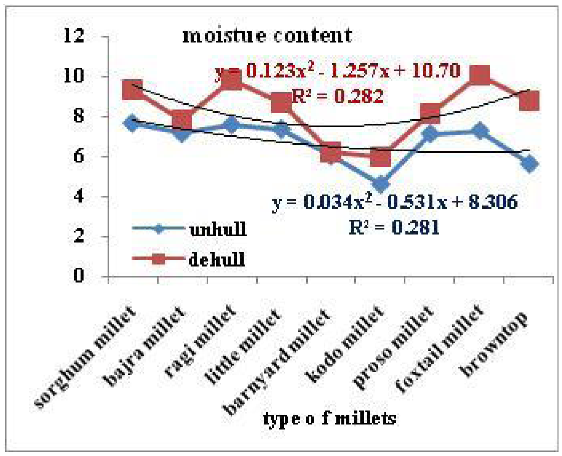

Fig. 1. Moisture content of different millets

Table 1. Dehulling parameters of different minor millets at 21Hz speed

SNo.	speed	type of millet	d. eff.	hrr	brr	uhrr	per.in.	cap.
1	21 Hz	Proso Millet	96.30	25.35	12.79	65.70	24.41	72.43
2		Kodo Millet	98.74	0.76	16.49	84.02	0.75	66.96
3		Little Millet	97.20	19.13	11.92	71.83	18.60	44.15
4		Foxtail Millet	95.25	13.39	20.72	70.88	12.75	58.71
5		Barnyard Millet	95.45	5.67	17.35	81.74	5.41	61.97
		average	96.59	12.86	15.86	74.83	12.39	60.84
		maximum	98.74	25.35	20.72	84.02	24.41	72.43
		minimum	95.25	0.76	11.92	65.70	0.75	44.15
		sem	0.64	4.44	1.60	3.47	4.29	4.78
		sd	1.43	9.92	3.58	7.75	9.58	10.68
		cv	1.48	77.14	22.56	10.35	77.38	17.55

Table 2. Dehulling parameters of different minor millets at 28Hz speed

SNo.	Speed	Type of millet	Deh eff.	hrr	brr	uhrr	per.ind.	capacity
1	28 Hz	Proso Millet	88.46	60.33	20.64	32.08	53.37	61.72
2		Kodo Millet	97.25	4.51	5.72	92.60	4.38	69.95
3		Little Millet	90.80	57.71	19.57	32.85	52.40	63.52
4		Foxtail Millet	94.00	54.78	8.88	42.72	51.49	66.22
5		Barnyard Millet	90.85	28.11	19.76	62.20	25.54	69.04
		average	92.27	41.09	14.91	52.49	37.44	66.09
		maximum	97.25	60.33	20.64	92.60	53.37	69.95
		minimum	88.46	4.51	5.72	32.08	4.38	61.72
		sem	1.52	10.82	3.15	11.40	9.77	1.57
		sd	3.41	24.19	7.05	25.50	21.85	3.51
		cv	3.69	58.87	47.28	48.58	58.36	5.31

hulling efficiency and milling efficiency. Hulling efficiency is a measure of only hull removal, the milling efficiency(Em) includes both dehulling and yield of finished product (dehulled, split and unsplit grain) during milling. Dehulling efficiency depends upon extent of husk removed, weight of unhulled and dehulled grains, extent of brokens and powder formation (Mangaraj *et al.,* 2017).

The variable frequency drive is connected to the dehuller drive pulley and the speed is varied at different levels, 21Hz, 28Hz and 35Hz and the corresponding dehulling efficiency was worked out. (Table 1-3) Performance index and the capacity of the double head dehuller were worked out. Weight of the husk, dehulled sample, (HRR), broken rice recovery (BRR)and unhulled rice recovery (URR) were worked out. The cleaner cum grader cum aspirator separates the brokens from the head rice. The brokens are sieved to separate the major brokens and the minor brokens. The brokens, husk and the dehusked head rice sample were separately weighed and put in separate ziplock polyethylene see through covers and stored in refrigerated conditions. The time for dehulling was recorded using stop watch.

Head rice recovery after dehulling of 1kg of raw millet is the lowest for kodo millet, 8.15% ±5.62 followed by barnyard millet, 26.07%±11.24,foxtail millet, 46.04%±16.90, proso millet, 53.19%±14.46 and little millet, 53.73%±11.93. Kodo millet is difficult to dehull since many layers are present and the amount of head rice obtained is less compared to other minor millets. Broken rice recovery for proso millet ranged between 7.59 to 12.3%±1.39, for kodo millet, it is 5.72 to 16.49%±3.31, for little millet it ranged between 11.92 to 23.10%±3.30 for foxtail millet it is 8.88 to 20.72%±3.73 and 5.41 to 38.54%±7.64 in barnyard millet. Brokens are more in barnyard millet since the moisture content is more in that millet. Performance index varied between 24.41 to 63.27±11.26 for proso millet, 0.75 to 18.25±5.33,in kodo millet, 18.60 to 70.73 ±13.27, for little millet, 12.75 to 64.85 ± 15.62, for foxtail millet and 5.41 to 38.54±7.64 for barnyard millet (Table 4-8) Performance index is more in little millet since it is more efficient in dehusking compared to kodo millet that is difficult to dehusk since the bonding between the outer husk and the inner cotyledon is tough to separate in one pass and also without pre treatment.

Table 3. Dehulling parameters of different minor millets at 35Hz speed

SNo.	speed	type of millet	d.eff.	hrr	brr	uhrr	per.ind.	capacity
1	35 Hz	Proso Millet	85.64	73.88	28.97	13.92	63.27	63.21
2		Kodo Millet	95.20	19.17	14.49	71.39	18.25	71.68
3		Little Millet	83.85	84.35	23.10	11.81	70.73	63.70
4		Foxtail Millet	92.70	69.96	19.31	18.61	64.85	62.49
5		Barnyard Millet	86.75	44.43	35.62	35.23	38.54	56.32
		average	88.83	58.36	24.30	30.19	51.13	63.48
		maximum	95.20	84.35	35.62	71.39	70.73	71.68
		minimum	83.85	19.17	14.49	11.81	18.25	56.32
		sem	2.18	11.79	3.69	11.09	9.90	2.45
		sd	4.87	26.37	8.25	24.80	22.13	5.47
		cv	5.48	45.18	33.97	82.14	43.29	8.61

Table 4. Dehulling parameters of different minor millets at three different speeds

SNo.	Type of millet	speed	d.eff.	hrr	brr	uhrr	per.in	cap.
1	**Proso Millet**	21 Hz	96.00	25.35	12.79	65.70	24.41	72.43
2		28 Hz	88.00	60.33	20.64	32.08	53.37	61.72
3		35 Hz	86.00	73.88	28.97	13.92	63.27	63.21
	average		87.00	67.10	24.81	23.00	58.32	62.47
	maximum		96.00	73.88	28.97	32.08	63.27	72.43
	minimum		86.00	25.35	12.79	13.92	24.41	61.72
	sd		5.29	25.04	8.09	26.27	20.19	5.80
	sem		3.06	14.46	4.67	15.17	11.66	3.35
	cv		6.08	37.32	32.62	114.23	34.63	9.29

Testing and evaluation of millet dehullers

(1) Dehulling efficiency = $\frac{\text{weight of total hulled grain (head grain + broken grain)}}{\text{weight of grain fed into the dehuller hopper}} \times 100$

(2) Head grain recovery = $\frac{\text{weight of total hulled head grain}}{\text{weight of total hulled grain (head grain + broken grain)}} \times 100$

(3) Broken grain = $\frac{\text{weight of total hulled broken grain}}{\text{weight of total hulled grain (head grain+ broken grain)}} \times 100$

(4) Dehuller performance index = $\frac{\text{Dehulling efficiency x head rice recovery}}{100}$

(5) Capacity = $\frac{\text{weight of grain fed into the dehuller hopper kg/h}}{\text{time taken to dehull grain}}$ (Ogunjirin *et al.*, 2021)

(6) UHRR = $\frac{\text{Weight of the undehulled grain} \times 100}{\text{Initial weight of the sample}}$ (Mangaraj *et al.*, 2017)

hrr–head rice recovery, brr-broken rice recovery, uhrr-unhulled rice recovery, per.in –perf ormance index

The dehulling efficiency ranged between 95.25 to 98.74% for the 3 different speeds. This coincided with the earlier findings of Babatunde and Olamigoke, 2021 for roasted groundnut shelling of 94-96%. The dehulling efficiency is less in 35Hz speed among the 3 different speeds that were tested for all selected minor millets of proso, kodo, little, foxtail and barnyard millets. The efficiency is maximum in 21Hz speed and minimum in 35Hz speed. This may be due to lower the speed, the contact between the grain and the dehuller is expected o be more for effective dehulling to take

Table 5. Dehulling parameters of different minor millets at three different speeds

SNo.	Kodo Millet	speed	deh eff.	hrr	brr	uhrr	per.ind.	capacity
1		21 HZ	99.00	0.76	16.49	84.02	0.75	66.96
2		28 HZ	97.00	4.51	5.72	92.60	4.38	69.95
3		35 Hz	95.00	19.17	14.49	71.39	18.25	71.68
	average		97.00	8.15	12.23	82.67	7.79	69.53
	maximum		99.00	19.17	16.49	92.60	18.25	71.68
	minimum		95.00	0.76	5.72	71.39	0.75	66.96
	sd		2.00	9.73	5.73	10.67	9.24	2.39
	sem		1.15	5.62	3.31	6.16	5.33	1.38
	cv		1.19	68.95	27.04	7.45	68.41	1.98

Table 6. Dehulling parameters of different minor millets at three different speeds

SNo.	Little Millet	speed	deh eff.	hrr	brr	uhrr	per.ind.	capacity
1		21 HZ	97.20	19.13	11.92	71.83	18.60	44.15
2		28 HZ	90.80	57.71	19.57	32.85	52.40	63.52
3		35 Hz	83.85	84.35	23.10	11.81	70.73	63.70
	average		90.62	53.73	18.20	38.83	47.24	57.13
	maximum		97.20	84.35	23.10	71.83	70.73	63.70
	minimum		83.85	19.13	11.92	11.81	18.60	44.15
	sd		6.68	32.79	5.72	30.45	26.44	11.24
	sem		3.85	18.93	3.30	17.58	15.27	6.49
	cv		4.25	35.24	18.13	45.28	32.32	11.36

Table 7. Dehulling parameters of different minor millets at three different speeds

SNo.	Foxtail Millet	speed	d.eff.	hrr	brr	uhrr	per.ind.	capacity
1		21 HZ	95.00	13.39	20.72	70.88	12.75	58.71
2		28 HZ	94.00	54.78	8.88	42.72	51.49	66.22
3		35 Hz	93.00	69.96	19.31	18.61	64.85	62.49
	average		94.50	34.08	14.80	56.80	32.12	62.46
	maximum		95.00	69.96	20.72	70.88	64.85	66.22
	minimum		93.00	13.39	8.88	18.61	12.75	58.71
	sd		1.00	29.28	6.47	26.16	27.06	3.76
	sem		0.58	16.90	3.73	15.10	15.62	2.17
	cv		0.61	49.60	25.23	26.59	48.64	3.47

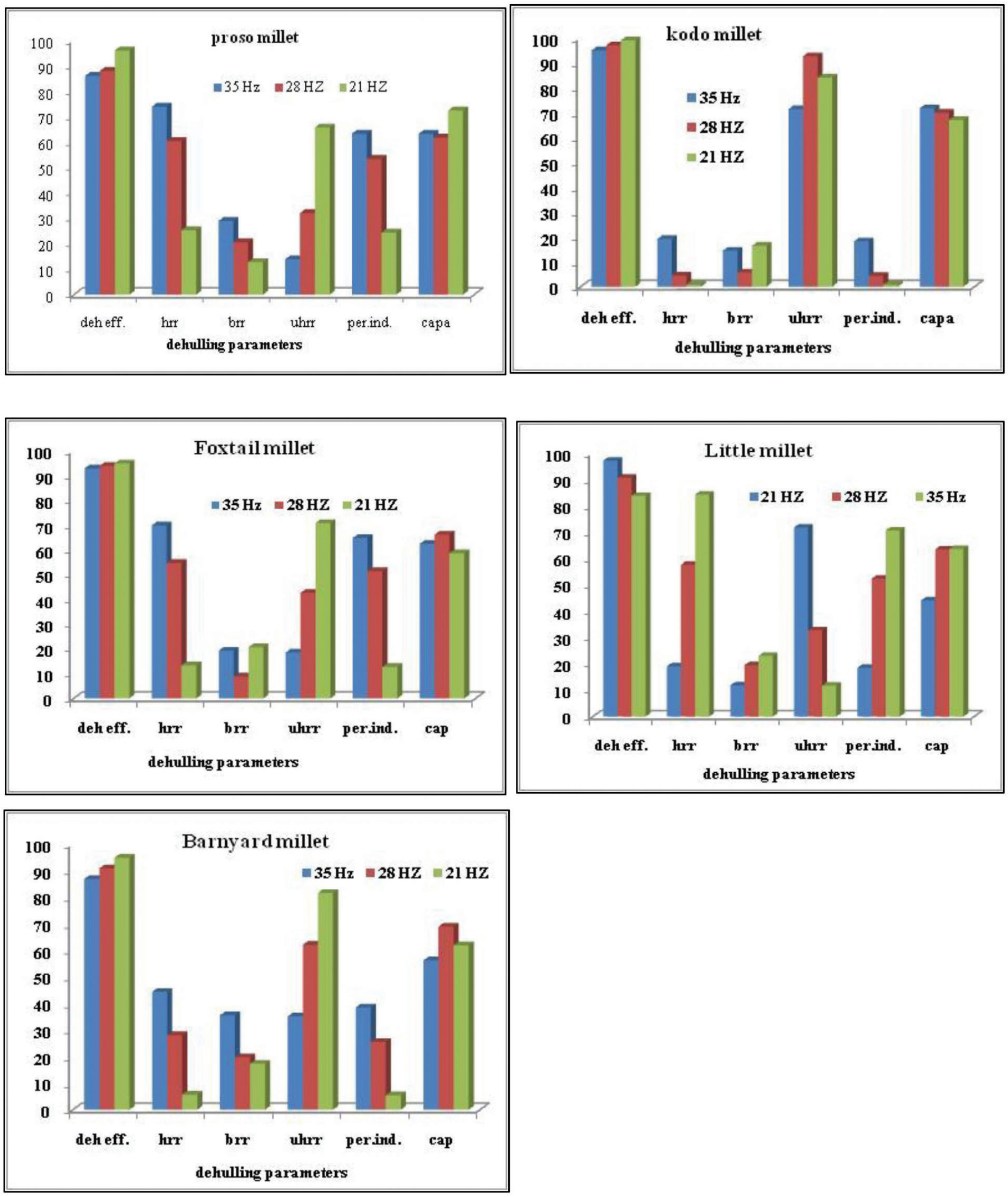

Fig. 2. Performance comparision of dehulling parameters of dhan foundation dehuller of selected millets at different speeds

place and at higher speed of 35Hz the time of contact between the grain and the dehuller is less and dehulling efficiency is less. Among the grains tested, little millet dehulling efficiency is less, 83.85% since the grain size is small as compared to other selected millets. Performance comparision of dehulling parameters of dhan foundation dehuller of selected millets at different speeds are shown in Fig. 2.

The head rice recovery using dhan foundation dehuller among the three different speeds of 21, 28 and 35Hz,proso millet has the higher HRR in 21Hz and 28Hz speed and at 35Hz speed, little millet has the highest HRR. Little millet outside husk is very light and less and hence efficient HRR of higher amount is obtained. Brokens are more in foxtail millet at 21Hz speed, 28Hz speed in proso millet, in barnyard millet at 35Hz speed. Brokens are more at 35Hz speed as compared to other 2 speeds among the selected millets. Riechert *et al.*, (1979) showed

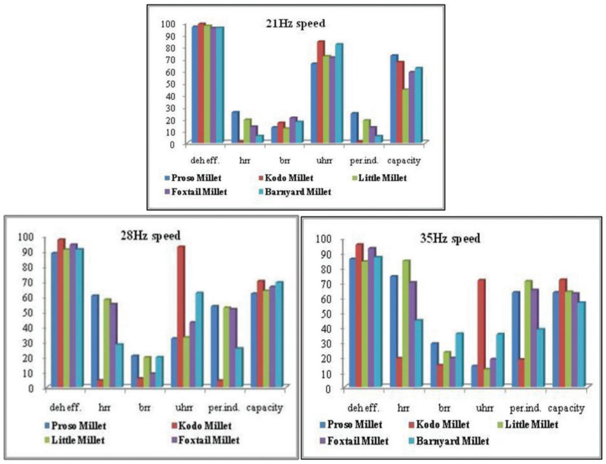

Fig. 3. Performance comparision of dhan foundation dehuller of selected millets at different speeds

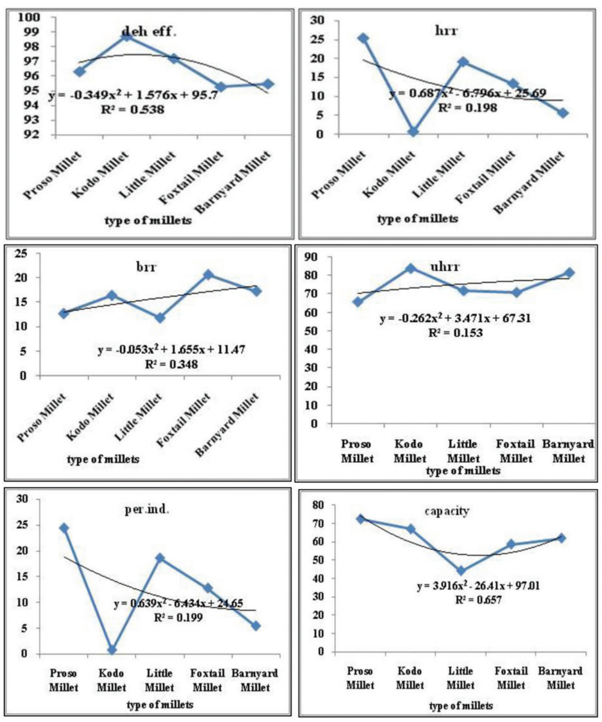

Fig. 4. Performance comparision of different dehulling parameters of dhan foundation dehuller of selected millets at different speeds

that de -hulling of cowpeas at a lower speed (450rpm) was more efficient than at a higher speed (770 or 1050rpm). Performance comparision of dhan foundation dehuller of selected millets at different speeds as shown in Fig. 3.

Unhulled rice recovery is more in kodo millet, 84.02 at 21Hz speed, at 28Hz, 92.0% at 35Hz speed it is 71.39%. This may require one more pass for complete dehulling of kodo millet, since 7-8 layers are present in kodo millet than all other types of millets. The brokens % and dehulling ˜ is determined for dehulling in impact type of dehuller and this coincided with the earlier findings of Douglas *et al.*, (2001). The dehulling efficiency indicates the extent of dehulling.

Fig. 5. Dhan foundation dehuller

Performance index is more in proso millet, 24.41 at 21Hz speed, at 28Hz speed, 53.37 at 35Hz 70.73 in little millet. Performance index is highest at 35Hz speed among the 3 speeds tested and in little millet among all the selected 5 minor millets. Performance index is a measure of HRR, BRR and URR of the selected millets and this gives a clear picture of the level of speed to be selected and the type of minor millet to be selected for dehulling in a dhan foundation dehuller. Performance comparision of different dehulling parameters of dhan foundation dehuller of selected millets at different speeds as shown in Fig. 4.

Capacity is more in proso millet at 21Hz speed, 72.43kg/h at 28Hz speed in kodo millet, 69.95kg/h and at 35Hz speed in kodo millet 71.68kg/h. Among the 3 speeds tested, 21Hz speed the capacity is the highest in proso millet dehulling as compared to other minor millet grains. This may be due to the size of the proso millet being higher as compared to other minor millet grains for dehulling in dhan foundation dehuller. The capacity of the millets dehuller coincided with the earlier findings of African bread fruit seeds that is the dehulling was found to be 64 kg/h. (Omobuwajo *et al.*, 1999). Motor efficiencies at a constant rpm changes as the load changes. The efficiency of a typical motor peaks at about 75% load, but drops rapidly below some

Table 8. Dehulling parameters of different minor millets at three different speeds

SNo.	Barnyard	Speed	Deh eff.	hrr	brr	uhrr	per.ind.	capacity
1		21 HZ	95.00	5.67	17.35	81.74	5.41	61.97
2		28 HZ	91.00	28.11	19.76	62.20	25.54	69.04
3		35 Hz	87.00	44.43	35.62	35.23	38.54	56.32
	average		93.00	16.89	18.56	71.97	15.48	65.50
	maximum		95.00	44.43	35.62	81.74	38.54	69.04
	minimum		87.00	5.67	17.35	35.23	5.41	56.32
	sd		4.00	19.46	9.93	23.35	16.69	6.37
	sem		2.31	11.24	5.73	13.48	9.64	3.68
	cv		2.48	66.52	30.88	18.73	62.27	5.62

threshold. Variable frequency drive controllers generate heat through their inefficiencies. It coincides with the earlier findings of, for the average condition when a motor is subjected to varying loads, the efficiencies of a motor that is operated by a VFD controller will be about the same as the

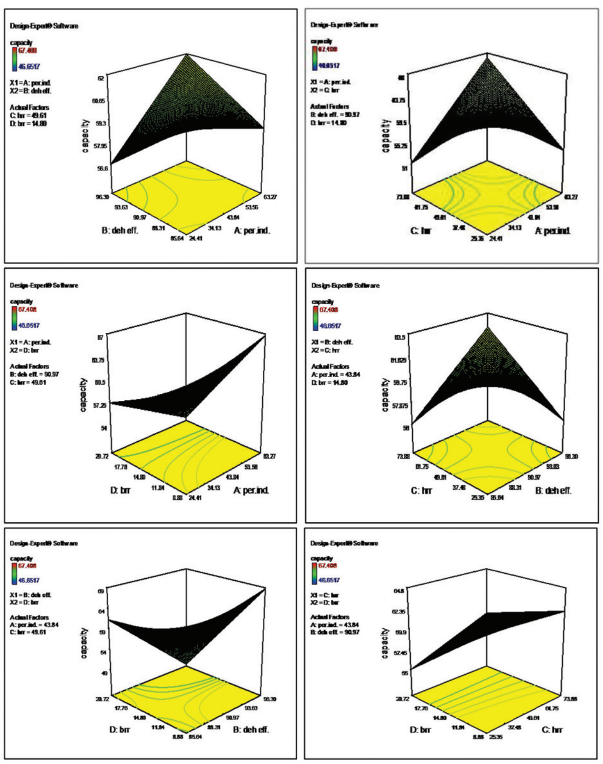

Fig.6. Capacity and machine evaluation parameters at selected 3 different speeds for proso millet.

efficiency of a motor that is operated across the line. However, motors operate with either a higher or lower relative efficiency and simultaneously being controlled by a VFD controller instead of operating across the line (Charles Burt *et al.*, 2008).

CONCLUSION

It is evident from the study,commercially available variable frequency drive (VFD) controllers are available that provide significant improvement of the power factor of motors. Commercially available VFD controllers maintain high efficiencies across practical ranges of loads and frequencies. At 21Hz speed, the capacity is more in proso millet, 72.43kg/h±4.78 followed by kodo millet, 66.96kg/h±4.78, barnyard millet, 61.97 kg/h±4.78, foxtail millet, 58.7 kg/h±4.78 and little millet,44.15kg/h±4.78. At 28Hz the capacity is more in kodo millet, 69.95 kg/h±1.57 followed by barnyard millet, 69.04kg/h±1.57, foxtail millet, 66.22kg/h±1.57, little millet, 63.52 kg/h±1.57 and proso millet, 61.72kg/h±1.57. At 35Hz the capacity is more in kodo millet, 71.68 kg/h±2.45 followed by little millet, 63.7kg/h±2.45, proso millet, 63.21kg/h ±2.45, foxtail millet, 62.49kg/h±2.45 and barnyard millet, 56.32 kg/h±2.45. This study shows that there is a consistent saving of power in dehulling of minor millets compared to dehuller operated without VFD in dhan foundation dehuller. The time of dehulling is reduced with the increase in speed among the 3 selected speeds taken for study.

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