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Research Paper :

Study on milling techniques for finger millets (*Eleusine coracana*)

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ABSTRACT

Flour mill (laboratory model) was evaluated for its milling performance for two ragi varieties GPU-28 and L-15 under different plate clearances, feed rates and plate speeds. Grinding plate clearances selected for the study were 0.3, 0.5 and 0.7mm, feed rates tested were 90, 100 and 115 kg/h and plate speeds taken were 450, 600 and 700 rpm. Flour mill was evaluated for its milling efficiency and milling loss under different combinations of plate clearances, feed rates and plate speeds. The flour recovery was recorded at each plate clearance, feed rate and plate speed combination. The different fractions of flour obtained from the above study were analyzed for their fineness modulus, nutritive value and consistency. Milling efficiency decreased with the increase in plate clearance. The increase in feed rate and plate speed increased the milling efficiency initially to an optimum level later on decreased with further increase in feed rate and plate speed. Milling efficiency decreased form 85.0 to 61.7 per cent and 83.7 to 61.9 per cent with the increase in plate clearance from 0.3 to 0.7 mm for GPU-28 and L-15 varieties of ragi, respectively. The maximum milling efficiency of 85.0 per cent was recorded at the combination of 600 rpm plate speed for GPU-28 and 83.7 per cent for L-15 ragi seeds. Fineness modulus of flour increased with the increase in plate clearance. As the feed rate and plate speed increased up to an optimum level, the fineness modulus decreased and further increase in feed rate and plate speed, increased the fineness modulus. Fineness modulus increased from 2.04 to 3.44 and 2.05 to 3.45 with the increase in plate clearance from 0.3 to 0.7 mm for the ragi flour from varieties GPU-28 and L-15, respectively. The least fineness modulus was recorded at 0.3mm clearance followed by 0.5 mm. Fineness modulus decreased from 2.18 to 2.04 and 2.21 to 2.05 with the increase in feed rate and attained the least value at a feed rate of about 100 kg/h for GPU-28 and L-15 ragi flours. Beyond this, the fineness modulus increased as the feed rate increased. Fineness modulus decreased from 2.36 to 2.04 and from 2.37 to 2.05 as the plate speed increased from 450 rpm to 600 rpm and it increased with further increase in plate speed in case of both the varieties of ragi. The fineness modulus recorded the least values of 2.04 and 2.05 at 600 rpm plate speed for GPU-28 and L-15 varieties ragi flour, respectively.

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Key words : Milling efficiency, Milling loss, Feed rate, Fineness modulus

The grain milling requirement of almost 80 per cent countries is being met being conventional milling using "Burr mill" operated by either mechanical or electrical energy. Not much recent information is available on threshing and milling of small sized millets. Flour mill fitted with cast steel plates and emery stones have since successfully replaced the stone discs made from natural red stones. There are good numbers of conventional types of flour mills are used in urban and rural areas. The overall efficiency of these mills was found to be very low and requires improvements. In the recent years milling technology has sufficiently advanced. The development of cast steel plates on which the radial grooves of the same width, beginning from periphery running up to the centre is a significant improvement to increase the overall milling efficiency of small domestic flour mills.

The milling efficiency not only depends on the hardness on the grain to be milled but also on the material hardness and sharpness of the radial groove on the plate surface (Ramkumar *et al.*, 1997). The cast steel plates/ emery stones can be moulded to the desired shape, size and hardness. The properties of these stones can thus be controlled by the selection of appropriate quality raw materials through good manufacturing practices.

Kurein and Desikachar (1966) studied the preparation of refined white flour from ragi using a laboratory mill. Refined, bran-free white flour was obtained from ragi in 60-70 per cent yield after conditioning the grain with water and grinding in a laboratory mill. The refined flour was rich in calcium (2.4%) but the protein content was low (4%). The shorts and husk fractions, which are rich in protein, were wet processed to extract an edible fraction in yield of 5 to 8 per cent. Flour obtained from roller mill was the whitest followed by hammer mill and plate grinder. Ram Kumar *et al.* (1997) studied the performance evaluation of domestic grinding for milling of ragi into flour using laboratory model burr mill and found the optimum values of clearance, feed rate and moisture content 0.5 mm, 100 kg/h and 10.7 per cent, respectively. The milling efficiency at the optimum values was 86 per cent. They observed that a fineness modulus of 1.77 was achieved at the feed rate of 112 kg/h and moisture content of 9.8 per cent (wb). Paulsen and Hill (1985) studied the corn quality factors affecting dry milling performance and they found that the yield of large flaking grits was significantly increased by selecting maize with low breakage susceptibility and high test weight. In order to incorporate the above mechanical properties into the cast steel plates, the local manufactures have to choose the correct material composition and the heat treatments in the manufacturing process.

METHODOLOGY

The experiment was conducted with two varieties of ragi *viz.*, GPU-28 and L-15 for milling operation by using laboratory model small scale burr mil and traditional method of milling (chakki). The milling was experimented at 3 different plate speeds, plate clearances and feed rates.

Milling by manual operated mill (Chakki):

Two varieties of ragi *viz.*, GPU-28 and L-15 were cleaned and samples of 1 kg each were taken for milling performance using traditional mill (chakki). Milling was done manually with uniform feed rate and speed of rotation. The flour around the mill after milling was collected for the analysis of milling efficiency, fineness modulus, nutritive value and consistency.

Milling by laboratory model mill:

A locally available flour mill ("Supreme grind well" manufactured by Chowdhry, JUC, India) was selected for the study. This is a burr type mill having one stationary and one rotating cast steel plate positioned vertically.

The cast steel plates have radial grooves which allow the raw material to pass out through an outlet. The grains were fed into the hopper, from where it passes on to the screw conveyor to deliver the feed material in between the two plates and further to the outlet due to centrifugal action. The prime move of the mill was 2 hp electric motor (Induction type) and power transmission is by means of V-belt and pulley. The detailed specifications of the mill and cast steel plates were as follows:

Design features of cast steel plates:

Weight	:	1.95 kg
Diameter	:	9.71 cm
Thickness	:	1.1 cm

Profile of grinding surface:

Number of primary furrows	:	12
Shape of furrows	:	radial
Furrow grooves	:	2.2 mm
Number of secondary furrows for each primary furrow	:	6
Size of eye piece (diameter)	:	7.32 cm

Feeding arrangement:

Type of feeding to the milling plates	:	Screw conveyor
Feed rate arrangement	:	By varying the plate gap of feeding mechanism

Plate clearance:

Clearance adjustment	:	By adjusting the spring loaded wheel knob
Mechanism and clearance	:	By adjusting the wheel knob fitted to the movable plate and the range varied from 0.3 to 2 cm

Speed of grinding plate:

Arrangement of speed	:	Using stepped V-grooved pulley fitted to the prime mover having three sizes
Speed obtainable	:	450,600 and 700 rpm

Treatments:

The following were the details of treatment employed during the study

Crop: Ragi:

Variety : a) GPU-28
b) L-15

Milling method:

– Traditional method of milling (Chakki)

– Milling with laboratory model burr mill

The following were the parameters considered for the milling study using laboratory model mill

Speed of rotation of milling plate (S), rpm:

$S_1 = 450$

$S_2 = 600$

$S_3 = 700$

Clearance between plates (C), mm:

$C_1 = 0.3$

$C_2 = 0.5$

$C_3 = 0.7$

Feed rate (F), kg/h:

$F_1 = 90$

$F_2 = 100$

$F_3 = 115$

The experiment was conducted in Factorial Completely Randomized Design (FCRD), having plate speed, plate clearance and feed rate as treatments.

The total number of treatment combinations = 27x2 = 54

Preparation of samples:

After cleaning the ragi using air screen cleaner to remove the impurities like thrash, dirt and dust, the 54 samples (each variety 27 samples, 9 clearance on milling efficiency, 9 for feed rate on milling efficiency and 9 samples for plate speed on milling efficiency) of 1 kg each were weighed and taken in cloth bags.

Milling of ragi samples:

After trial and error the samples (1 kg each) of GPU-28 were milled at three different plate speeds (450,600 and 700 rpm). Fixing plate speed at 450 rpm, milling was done for three different feed rates (90, 100 and 115 kg/h) by adjusting 0.3 mm plate clearance and the flour was collected through the outlet in a separate cloth bags. Again, by adjusting wheel knob to other clearances (0.5 and 0.7 mm), milling was done to three feed rates. Changing the plate speed to 600 and 700 rpm milling was repeated for 3 feed rates and three clearances for GPU-28 ragi variety. The same procedure was repeated for L-15 ragi variety also.

The flour samples after milling were sieved using BS 30 sieve and analyzed for milling efficiency at different plate clearances, plate speeds and feed rates.

RESULTS AND DISCUSSION

The results obtained from the present investigation are summarized below :

Milling by manual operated mill (chakki):

The milling efficiency of 71 per cent was obtained in traditional mill (chakki) as compared to 85 per cent in flour mill (laboratory model) for GPU-28 ragi grain. For L-15 ragi grains, the efficiency was 69 per cent and 83.7 per cent in traditional mill and laboratory model mill, respectively (Table 1 and 2).

Milling by laboratory model mill at different operating conditions:

Effect of plate clearance on milling efficiency and

Table 1 : Evaluation of milling of ragi by manual operated mill (chakki)

Sr. No.	Quality	Ragi variety	
		GPU-28	L-15
1.	Milling efficiency (%)	71	69
2.	Fineness modulus of flour	2.516	2.610
3.	Nutritive Value of flour		
	Calcium (%)	0.61	-
	Phosphorus (%)	0.30	-
	Protein (%)	11.51	-
4.	Consistency of flour (cm)	9.15	10.14

Table 2 : Comparative study of milling of two varieties of ragi by manual operated mill (chakki) and laboratory model mill

Sr. No.	Quality	Variety GPU-28		Variety L-15	
		Chakki	Lab. mill	Chakki	Lab. mill
1.	Milling efficiency (%)	71.0	85.0	69.0	83.7
2.	Fineness modulus of flour	2.516	2.044	2.610	2.056
3.	Nutritive value of flour				
	Calcium (%)	0.61	0.49	-	-
	Phosphorus (%)	0.30	0.23	-	-
	Protein (%)	11.51	11.38	-	-
4.	Consistency of flour (gel spread, cm)	9.15	10.16	10.14	11.25

milling loss:

Milling efficiency of ragi decreased significantly with the increase in plate clearance. As the plate clearance increased from 0.3 to 0.7 mm, the milling efficiency decreased from 85.0 to 61.7 per cent in case of GPU-28 variety seeds(Table 4). The maximum milling efficiency of 85.0 per cent was obtained at 0.3 mm clearance followed by 0.5 mm (82.2%). The milling efficiency decreased from 83.7 to 61.9 per cent in L-15 variety ragi seeds as the plate clearance increased from 0.3 to 0.7 mm (Table 8). It is obvious that, the percentage of whole split grains in the flour increased as the plate clearance increased and hence the milling efficiency decreased.

There was an appreciable increase in temperature of the milled product at the minimum clearance of 0.3 mm. this may cause detrimental effect on the quality of flour when stored. Further, the content of iron filings due to wear and tear of grinding plates and also noise due to aberration between the plates were observed more at the minimum clearance of 0.3 mm.

The milling loss increased significantly with the increase of plate clearance. It increased from 15 to 38.3 per cent (Table 4)as the clearance increased from 0.3 to 0.7 mm for GPU-28 variety seeds. The milling loss observed was maximum (38.3%) at 0.7mm clearance. In case of L-15 variety seeds, the milling loss increased from 0.3 to 0.7 mm. The higher milling loss at higher clearance might be due to the fact that the necessary shear and compression force may not be sufficient for proper grinding. As a result, the higher clearance resulted in higher percentage of whole seeds and coarser grinding to increase the milling loss. The results of milling loss and

Table 3 : Effect of plate clearance and feed rate on milling efficiency and milling loss of GPU-28 ragi seeds at 450 rpm plate speed

Treatments	Flour recovery (kg)	Milling loss (kg)	Milling loss (%)	Milling efficiency (%)
Plate clearances				
C_1 = 0.3 mm	0.758	0.243	24.2	75.8
C_2 = 0.5 mm	0.747	0.253	25.3	74.7
C_3 = 0.7 mm	0.428	0.572	57.2	42.8
F test			*	*
S.E.±			0.621	0.3655
C.D. (P=0.05)			0.1863	1.0956
Feed rate				
F_1 = 90 kg/h	0.741	0.259	25.9	74.1
F_2 = 100 kg/h	0.758	0.242	24.2	75.8
F_3 = 115 kg/h	0.650	0.350	35.0	65.0
F test			*	*
S.E.±			0.0621	0.3655
C.D. (P=0.05)			0.1863	1.0956
C_1F_2	0.741	0.259	25.9	74.1
C_1F_2	0.741	0.259	25.9	74.1
C_1F_2	0.758	0.242	24.2	75.8
C_1F_3	0.650	0.350	35.0	65.0
C_2F_1	0.717	0.283	28.3	71.7
C_2F_2	0.747	0.253	25.3	74.7
C_2F_3	0.688	0.312	31.2	68.8
C_1F_1	0.418	0.582	58.2	41.8
C_2F_2	0.428	0.572	57.2	42.8
C_3F_3	0.427	0.573	57.3	42.7
F test			*	*
S.E.±			1.1076	0.6330
C.D. (P=0.05)			0.3226	1.8976

Note: C_1, C_2 and C_3 denote plate clearances
F_1, F_2 and F_3 denote feed rates
*denotes significant

Table 4 : Effect of plate clearance and feed rate on milling efficiency and milling loss of GPU-28 ragi seeds at 600 rpm plate speed

Treatments	Flour recovery (kg)	Milling loss (kg)	Milling loss (%)	Milling efficiency (%)
Plate clearances				
C_1 = 0.3 mm	0.850	0.150	15.0	85.0
C_2 = 0.5 mm	0.822	0.178	17.8	82.2
C_3 = 0.7 mm	0.617	0.382	38.3	61.7
F test			*	*
S.E.±			0.1493	0.6040
C.D. (P=0.05)			0.4476	1.8105
Feed rate				
F_1 = 90 kg/h	0.823	0.177	17.7	82.3
F_2 = 100 kg/h	0.850	0.150	15.0	85.0
F_3 = 115 kg/h	0.775	0.225	22.5	77.5
F test			*	*
S.E.±			0.1493	0.6040
C.D. (P=0.05)			0.4476	1.8105
C_1F_2				
C_1F_2	0.823	0.177	17.7	82.3
C_1F_2	0.850	0.150	15.0	85.0
C_1F_3	0.775	0.225	22.5	77.5
C_2F_1	0.790	0.210	21.0	79.0
C_2F_2	0.822	0.178	17.8	82.2
C_2F_3	0.776	0.224	22.4	77.6
C_1F_1	0.552	0.448	44.8	55.2
C_2F_2	0.617	0.383	38.3	61.7
C_3F_3	0.505	0.495	49.5	50.5
F test			*	*
S.E.±			1.1076	0.6330
C.D. (P=0.05)			0.3226	1.8976

Note: C_1, C_2 and C_3 denote plate clearances
F_1, F_2 and F_3 denote feed rates
*denotes significant

Table 5 : Effect of plate clearance and feed rate on milling efficiency and milling loss of GPU-28 ragi seeds at 700 rpm plate speed

Treatments	Flour recovery (kg)	Milling loss (kg)	Milling loss (%)	Milling efficiency (%)
Plate clearances				
C_1 = 0.3 mm	0.804	0.196	19.6	80.4
C_2 = 0.5 mm	0.773	0.227	22.7	77.3
C_3 = 0.7 mm	0.623	0.377	37.7	62.3
F test			*	*
S.E.±			0.1431	0.0652
C.D. (P=0.05)			0.4290	0.1955
Feed rate				
F_1 = 90 kg/h	0.787	0.213	21.3	78.7
F_2 = 100 kg/h	0.804	0.196	19.6	80.4
F_3 = 115 kg/h	0.758	0.242	24.2	75.8
F test			*	*
S.E.±			0.1431	0.0652
C.D. (P=0.05)			0.4290	0.1955
C_1F_2				
C_1F_2	0.787	0.213	21.3	78.7
C_1F_2	0.804	0.196	19.6	80.4
C_1F_3	0.758	0.242	24.2	75.8
C_2F_1	0.766	0.234	23.4	76.6
C_2F_2	0.773	0.227	22.7	77.3
C_2F_3	0.756	0.244	24.4	75.6
C_1F_1	0.580	0.420	42.0	58.0
C_2F_2	0.623	0.377	37.7	62.3
C_3F_3	0.570	0.430	43.0	57.0
F test			*	*
S.E.±			0.2429	0.1130
C.D. (P=0.05)			0.7431	0.3386

Note: C_1, C_2 and C_3 denote plate clearances
F_1, F_2 and F_3 denote feed rates
*denotes significant

milling efficiency were in conformity with the results obtained by Ramakumar *et al.* (1997) who reported that the higher plate clearance resulted in low milling efficiency due to high percentage of crushed grain in the product.

Effect of feed rate on milling efficiency and milling loss:

Milling efficiency of GPU-28 and L-15 ragi seeds increased significantly with the increase of feed rate to a certain level but decreased with further increase in feed rate. As the feed rate increased from90-100 kg/hr. The milling efficiency increased from 82.3 to 85.0 per cent (Table 4). Further, the increased feed rate from 100 to 115 kg/h decreased the milling efficiency from 85.0 to 77.5 (Table 4) per cent for GPU-28 ragi seeds. The highest milling efficiency was achieved at 100 kg/h feed rate. The effect of feed rate on milling efficiency of L-15 ragi seeds was also similar.

The low milling efficiency both at 90 and 115 kg/h feed rate might by due to the presence of high percentage of crushed and coarser grains. At the low feed rate of 90 kg/h, the grains supplied between the plates might be inadequate for proper grinding.

The milling loss decreased with the increase in feed rate and attained its minimum percentage at 100 kg/h beyond this, the milling loss increased. Increased feed rate from 90 to 100 kg/h, decreased the milling loss from 17.5 to 15.0 per cent and 18.6 to 16.3 per cent for GPU-

Table 6 : Effect of plate speed, plate clearance and feed rate on milling efficiency and milling loss Ragi: variety GPU-28

Treatments	Flour recovery (kg)	Milling loss (kg)	Milling loss (%)	Milling efficiency (%)
$S_1C_1F_1$	0.741	0.249	25.9	74.1
$S_1C_1F_2$	0.758	0.242	24.4	75.8
$S_1C_1F_3$	0.650	0.350	35.0	65.0
$S_1C_2F_1$	0.717	0.283	28.3	71.7
$S_1C_2F_2$	0.747	0.253	25.3	74.7
$S_1C_2F_3$	0.688	0.312	31.2	68.8
$S_1C_3F_1$	0.418	0.582	58.2	41.8
$S_1C_3F_2$	0.428	0.572	57.2	42.8
$S_1C_3F_3$	0.427	0.573	57.3	42.7
$S_2C_1F_1$	0.823	0.177	17.7	82.3
$S_2C_1F_2$	0.850	0.150	15.0	85.0
$S_2C_1F_3$	0.775	0.225	22.5	77.5
$S_2C_2F_1$	0.790	0.210	21.0	79.0
$S_2C_2F_2$	0.822	0.178	17.8	82.2
$S_2C_2F_3$	0.776	0.224	22.4	77.6
$S_2C_3F_1$	0.552	0.448	44.8	55.2
$S_2C_3F_2$	0.167	0.238	23.8	61.7
$S_2C_3F_3$	0.505	0.495	49.5	50.5
$S_3C_1F_1$	0.787	0.213	21.3	78.7
$S_3C_1F_2$	0.804	0.196	17.9	80.4
$S_3C_1F_3$	0.758	0.242	24.2	75.8
$S_3C_2F_1$	0.766	0.234	23.4	76.6
$S_3C_2F_2$	0.773	0.227	22.7	77.3
$S_3C_2F_3$	0.756	0.244	24.4	75.6
$S_3C_3F_1$	0.580	0.420	42.0	58.0
$S_3C_3F_2$	0.623	0.377	37.7	62.3
$S_3C_3F_3$	0.570	0.430	43.0	57.0
F test			*	*
S.E.±		0.9167		
C.D. (P=0.05)		0.2540+01		

Note: C_1, C_2 and C_3 denote 0.3, 0.5 and 0.7 mm plate clearance
F_1, F_2 and F_3 denote 90, 100 and 115 kg/h feed rates
S_1, S_2 and S_3 denote 450, 600 and 700 rpm plate speeds
*denotes significant

Table 7 : Effect of plate clearance and feed rate on milling efficiency and milling loss of L-15 ragi seeds at 450 rpm plate speed

Treatments	Flour recovery (kg)	Milling loss		Milling efficiency (%)
		(kg)	(%)	
Plate clearances				
C_1 = 0.3 mm	0.758	0.242	24.2	75.8
C_2 = 0.5 mm	0.757	0.243	24.3	75.7
C_3 = 0.7 mm	0.427	0.573	57.3	42.7
F test			*	*
S.E.±			0.0941	0.1024
C.D. (P=0.05)			0.2820	0.3070
Feed rate				
F_1 = 90 kg/h	0.749	0.251	25.1	74.9
F_2 = 100 kg/h	0.758	0.242	24.2	75.8
F_3 = 115 kg/h	0.690	0.310	31.0	69.0
F test			*	*
S.E.±			0.0941	0.1024
C.D. (P=0.05)			0.2820	0.3070
C_1F_2				
C_1F_2	0.749	0.251	25.1	74.9
C_1F_2	0.758	0.242	24.2	75.8
C_1F_3	0.690	0.310	31.0	69.0
C_2F_1	0.725	0.275	27.5	72.5
C_2F_2	0.757	0.243	24.3	75.7
C_2F_3	0.656	0.344	34.4	65.6
C_1F_1	0.398	0.602	60.2	39.8
C_2F_2	0.427	0.573	57.3	42.7
C_3F_3	0.429	0.571	57.1	42.9
F test			*	*
S.E.±			0.1630	0.1777
C.D. (P=0.05)			0.4885	0.5318

Note: C_1, C_2 and C_3 denote plate clearances
F_1, F_2 and F_3 denote feed rates
*denotes significant

Table 8 : Effect of plate clearance and feed rate on milling efficiency and milling loss of L-15 ragi seeds at 600 rpm plate speed

Treatments	Flour recovery (kg)	Milling loss		Milling efficiency (%)
		(kg)	(%)	
Plate clearances				
C_1 = 0.3 mm	0.837	0.163	16.3	83.7
C_2 = 0.5 mm	0.826	0.174	17.4	82.6
C_3 = 0.7 mm	0.619	0.381	38.1	61.9
F test			*	*
S.E.±			0.0745	0.1002
C.D. (P=0.05)			0.2235	0.300
Feed rate				
F_1 = 90 kg/h	0.814	0.186	18.6	81.4
F_2 = 100 kg/h	0.837	0.163	16.3	83.7
F_3 = 115 kg/h	0.784	0.216	21.6	78.4
F test			*	*
S.E.±			0.0745	0.1002
C.D. (P=0.05)			0.2235	0.300
C_1F_2				
C_1F_2	0.814	0.186	18.6	81.4
C_1F_2	0.837	0.163	16.3	83.7
C_1F_3	0.784	0.216	21.6	78.4
C_2F_1	0.783	0.216	21.6	78.3
C_2F_2	0.826	0.714	17.4	82.6
C_2F_3	0.775	0.225	22.5	77.5
C_1F_1	0.559	0.441	44.1	55.9
C_2F_2	0.619	0.381	38.1	61.9
C_3F_3	0.516	0.484	48.4	57.6
F test			*	*
S.E.±			0.1291	0.1736
C.D. (P=0.05)			0.3870	0.5203

Note: C_1, C_2 and C_3 denote plate clearances
F_1, F_2 and F_3 denote feed rates
*denotes significant

28 and L-15 ragi varieties, respectively. Further, increase in feed rate from 100 to 115 kg/h, increased the milling loss from 15 to 22.5 and 16.3 to 21.6 pr cent for both the varieties, respectively. The high milling loss at high feed rate might be due to the fact that there was an increased force due to high feed rate which forced the grain to come out from the plates without giving required residence time.

Effect of plate speed on milling efficiency and milling loss:

Effect of plate clearance on milling efficiency was also similar to that of feed rate. As the plate speed increased, the milling efficiency increase up to a certain level and further increase in plate speed resulted in decreased milling efficiency. As the plate speed increased from 450 to 600 rpm the milling efficiency increased from 75.8 to 85 per cent and 75.8 to 83.7 per cent for GPU-28 and L-15 varieties, respectively (Table 3, 4, 7 and 8). Further, increase in plate speed from 600 to 700 rpm resulted in reduction in milling efficiency (Table 4 and 5) from 85.0 to 80.4 per cent from and 83.7 to 81.5 per cent for GPU-28 and L-15 varieties, respectively (Table 3, 4, 7 and 8). The high milling efficiency at optimum speed of 600 rpm might be attributed to the fact that there was a correlation between feed rate and plate speed such that it gave adequate residence time and shear and compressive forces just sufficient enough to grind the seeds properly.

Milling loss decreased as the plate speed increased up to the optimum level but, it increased with further

Table 9 : Effect of plate clearance and feed rate on milling efficiency and milling loss of L-15 ragi seeds at 700 rpm plate speed

Treatments	Flour recovery (kg)	Milling loss (kg)	Milling loss (%)	Milling efficiency (%)
Plate clearances				
C_1 = 0.3 mm	0.815	0.185	18.5	81.5
C_2 = 0.5 mm	0.777	0.223	22.3	77.7
C_3 = 0.7 mm	0.626	0.374	37.4	62.6
F test			*	*
S.E.±			0.0172	0.1393
C.D. (P=0.05)			0.3213	0.4177
Feed rate				
F_1 = 90 kg/h	0.801	0.199	19.9	80.1
F_2 = 100 kg/h	0.815	0.185	18.5	81.5
F_3 = 115 kg/h	0.769	0.231	23.1	76.9
F test			*	*
S.E.±			0.0172	0.1393
C.D. (P=0.05)			0.3213	0.4177
C_1F_2				
C_1F_2	0.801	0.199	19.9	80.1
C_1F_2	0.815	0.185	18.5	81.5
C_1F_3	0.769	0.231	23.1	76.9
C_2F_1	0.765	0.235	23.5	76.5
C_2F_2	0.777	0.223	22.3	77.7
C_2F_3	0.761	0.239	23.9	76.1
C_1F_1	0.588	0.412	41.2	58.8
C_2F_2	0.626	0.374	37.4	62.6
C_3F_3	0.577	0.423	42.3	57.7
F test			*	*
S.E.±			0.1856	0.2413
C.D. (P=0.05)			0.5564	0.7234

Note: C_1, C_2 and C_3 denote plate clearances
F_1, F_2 and F_3 denote feed rates
*denotes significant

Table 10 : Effect of plate speed, plate clearance and feed rate on milling efficiency and milling loss Ragi: variety L-15

Treatments	Flour recovery (kg)	Milling loss (kg)	Milling loss (%)	Milling efficiency (%)
$S_1C_1F_1$	0.749	0.251	25.1	74.9
$S_1C_1F_2$	0.758	0.242	24.2	75.8
$S_1C_1F_3$	0.690	0.310	31.0	69.0
$S_1C_2F_1$	0.725	0.275	27.5	72.5
$S_1C_2F_2$	0.757	0.243	24.3	75.7
$S_1C_2F_3$	0.656	0.344	34.4	65.6
$S_1C_3F_1$	0.395	0.602	60.2	39.8
$S_1C_3F_2$	0.427	0.573	57.3	42.7
$S_1C_3F_3$	0.429	0.571	57.1	42.9
$S_2C_1F_1$	0.814	0.186	18.6	81.4
$S_2C_1F_2$	0.837	0.163	16.3	83.7
$S_2C_1F_3$	0.784	0.216	21.6	78.4
$S_2C_2F_1$	0.783	0.217	21.7	78.3
$S_2C_2F_2$	0.826	0.174	17.4	82.6
$S_2C_2F_3$	0.775	0.225	22.5	77.5
$S_2C_3F_1$	0.559	0.441	44.1	55.9
$S_2C_3F_2$	0.619	0.381	38.1	61.9
$S_2C_3F_3$	0.516	0.484	48.4	51.6
$S_3C_1F_1$	0.801	0.199	19.4	80.1
$S_3C_1F_2$	0.815	0.185	18.5	81.5
$S_3C_1F_3$	0.769	0.231	23.1	76.9
$S_3C_2F_1$	0.765	0.235	23.5	76.5
$S_3C_2F_2$	0.777	0.223	22.3	77.7
$S_3C_2F_3$	0.761	0.239	23.9	76.1
$S_3C_3F_1$	0.588	0.412	41.2	58.8
$S_3C_3F_2$	0.626	0.374	37.4	62.6
$S_3C_3F_3$	0.577	0.423	42.3	57.7
F test			*	*
S.E.±			0.9167	
C.D. (P=0.05)			0.2540+01	

Note: C_1, C_2 and C_3 denote 0.3, 0.5 and 0.7 mm plate clearance
F_1, F_2 and F_3 denote 90, 100 and 115 kg/h feed rates
S_1, S_2 and S_3 denote 450, 600 and 700 rpm plate speeds
*denotes significant

increase in plate speed. As the plate speed increased from 450 to 600 rpm, the milling loss decreased from 24.2 to 15.0 per cent for GPU-28 ragi seeds and from 24.2 to 16.3 per cent for L-15 variety (Table- 3, 4, 7 and 8). Further increase in plate speed to 700 rpm resulted in increased milling loss of 19.6 and 18.5 per cent for the varieties GPU-28 and L-15, respectively (Table 5 and 9).

Interaction among plate clearance, feed rate and plate speed on milling efficiency and milling loss:

The three way interaction among plate clearance, feed rate and plate speed was significant. The combination of 600 rpm plate speed, 0.3 mm plate clearance and 100 kg/h feed rate recorded the highest milling efficiency (85%) and the lowest milling loss (15.0%). This was followed by 700 rpm plate speed, 0.3 mm clearance and 100 kg/h feed rate (80.4%) and (17.9%), respectively (Table 6).

Among the different treatment combinations, 450 rpm plate speed, 0.5 mm clearance and 100 kg/h feed rate ($S_1C_2F_2$), 600 rpm plate speed, 0.5 mm clearance and 100 kg/h feed rate ($S_2C_2F_2$) and 700 rpm plate speed, 0.5mm clearance and 100 kg/h feed rate ($S_3C_2F_2$), the highest milling efficiency and the lowest milling loss were recorded in $S_2C_1F_2$ combination and this combination was considered as optimum (Table 6).

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