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Effect of Moisture Content and Loading Rate on Grain Detachment and Rupture Force of Paddy

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ABSTRACT: Determination of grain detachment and rupture force must be performed before designing any threshing equipment. Such a study has been undertaken at College of Agricultural Engineering and Technology, OUAT, Bhubaneswar, India during Kharif 2019 and Rabi 2020. The grain detachment and rupture force of six varieties of paddy were determined at four levels of grain moisture content and three levels of loading rate by using Universal Testing Machine. The grain detachment force of single grain was measured for each variety at various grain moisture content at loading rate of 50,100 and 150 mm per min while the rupture force of each variety was determined at three loading rate of 10, 15 and 20 mm per min at same four levels of moisture content. It was observed that the grain detachment force was highest at higher moisture content of grain. This study showed that the detachment force increased with increase in moisture content whereas the rupture force decreased with increase in moisture content of paddy grain.

Keywords: detachment force, rupture force, pedicel, paddy, moisture content, loading rate

I. INTRODUCTION

Paddy (*Oryza sativa* L.) is an ancient and most important cereal crop. In Odisha, about 70% of the population depend on agriculture. Out of the total cultivable land of 61.80 lakh hectare, paddy covers 38.80 and 3.00 lakh hectare in Kharif and Rabi season respectively (Anonymous, 2014-15). Threshing is required to detach the grains from the bundle of panicles of any cereal crop particularly paddy and wheat. Threshing being one of the most important operations, largely affect grain loss and damage. For developing a thresher, it is important to design the appropriate size of the threshing cylinder and its threshing element along with its matching cleaning unit. For this purpose, the force required to detach the paddy grains from the panicle and the rupture force of grain are very important parameters to be considered. Hence, the recent study was undertaken to determine the detachment force and rupture strength of paddy by using Universal Testing machine (UTM).

Many researchers across the globe have studied to find the threshing and rupture force of agricultural products. Swain *et al.* (2020) conducted an experiment to study the strength properties of sorghum for designing a millet thresher. It was observed that tensile strength of sorghum stalk increased with increase in moisture content and rupture force of sorghum grain decreased with increase in moisture content. Ribeiro *et al*. (2019) assessed the mechanical properties of saccharine sorghum seeds at different moisture contents. Compressive tests were performed through uni-axial tests for a sample of 15 seeds at different moisture content. Their results indicated that the compressive force required to deform saccharine sorghum seeds decreased with increasing moisture content, whereas values of proportional modulus of deformity increased with both reduced moisture content and deformation. They also added that the reduction in moisture content caused an increase in the force required to rupture the seeds. Alizadeh and Allameh (2011) measured the threshing force of paddy at three portions of panicles viz. upper, middle and lower part and three loading manners as tension, bending perpendicular to the front of the grain and bending perpendicular to the side of the grain. They concluded that the highest threshing force exhibits at lower portion of the panicle under tension loading and least threshing force at the upper portion of panicle. Tavakoli *et al.* (2009) studied the effect of moisture content and loading rate on fracture resistance of barley grains. The barley grains were quasi-statically loaded with two levels of loading rates 5 and 10 mm/min and four levels of moisture content 7.34, 12.11, 16.82, and 21.58% dry basis. It was observed

that the force required for initiating the grain rupture decreased from 161.97 to 93.94 N with the increase in the moisture content from 7.34 to 21.58% dry basis. Saiedirad *et al.* (2008) studied the effects of seed size, seed orientation, loading rate and moisture content on the force and energy required for fracturing cumin seed under quasi-static loading. Their results showed that seed rupture force decreased from 15.7 to 11.96 N with an increase in the moisture content from 5.7 to 15% dry basis. Fangping *et al.* (2004) studied the effect of harvesting time on the detachment force of grains from panicle. They opined that the moisture content of the grain has significant impact on the detachment force. Tsuneo *et al.* (2002) conducted a tensile test to determine the detaching force of a single grain of 20 varieties of paddy. Results revealed that the behaviour of detaching force is affected by the amount of water content in the stem and the variety of paddy and not affected by the tensile speed. Konak *et al.* (2002) evaluated several physical properties of chick pea seeds as function of moisture content. He revealed that the rupture force decreased with the increase in the moisture content of the chick pea seeds. The highest rupture force of chick pea seed was reported as 210 N with a moisture content of 5.2% dry basis. Szot *et al.* (1998)measured the threshing force of some Italian varieties of paddy and the results showed that the detaching force is higher at the lower portion of the panicle. Ichkawa *et al.* (1990) studied the threshing force and shattering habit of paddy grain by using two testing devices. First device had a threshing drum of 365 mm diameter, 440 mm width and 32 threshing teeth with a peripheral velocity of 12m/s, whereas the second method measured straight tension to quantify separating forces using TR-11. The study concluded that tension force is proportional to the degree of stiffness of the grains in the threshing operation. Waananen and Okos (1988) studied failure properties of yellow-dent corn kernels under uni-axial compressive loading at four levels of temperature and moisture content. He revealed that the failure stress of corn decreased and failure strain increased when moisture content and temperature increased. Lee and Huh (1984) investigated the threshing force of different rice varieties. Their study claimed that the threshing force required to detach the grains from panicles in tension is significantly higher than the one applied in bending condition. Prasad and Gupta (1973) studied the behaviour of paddy grain under quasi-static compressive loading. He opined that the maximum compressive strength of paddy grain decreased with increase in moisture content. It was found that the compressive strength of paddy grains varied from 40.6 to 160.7 N as the moisture content varies from 12-24% dry basis.

Although many studies have been conducted to determine the grain detachment and rupture force of paddy using different methods, but no study has been carried out to find the detachment and rupture force of paddy with respect to both grain moisture content and loading rate using Universal Testing Machine (UTM). Therefore, this study aimed to investigate the effect of moisture content and loading rate on the grain detachment and rupture force of different varieties of paddy prevailing in the state of Odisha by using Universal Testing Machine (make: Tinius Olsen, model: 5 kT, capacity: 5 kN).

MATERIALS AND METHODS

This study was carried out in College of Agricultural Engineering and Technology, OUAT, Bhubaneswar, India. Local popular rice varieties namely Lalat and Pratibha (long grain), Birupa and Pratikshya (medium grain), Sidhanta and Hasanta (short grain) were taken for the study to find the grain detachment force at various grain moisture contents. At the end of crop maturity, each paddy variety was harvested and collected from field. The panicles were randomly selected from the harvested paddy bundles and sealed in a plastic packet and tested on the same day in the laboratory. Firstly, the experiment was carried out to find the detachment force of paddy grain. As it is found from previous literature that maximum force is required to detach the grain from lower portion of the panicle, here in present study, detachment force of grain at lower portion of the panicle was determined. A single grain from lower portion of panicle were detached for each variety of paddy carefully by fixing a single grain with pedicle in lower fixture and upper part of panicle at upper fixture and pulling the panicle in upward direction by UTM. When upper fixture moves in upward direction, the grain gets detached from the panicle and the detachment force was recorded. Secondly, the experiment was carried out to find the rupture force of paddy grains. The individual grain of each variety was loaded between the two cross head and the compression plate. The grain was kept on the lower compression plate and the cross head moves towards the lower fixture plate. When the grain gets compressed and cracked, the rupture force was recorded (Fig. 1, 2 and 3). After the experiment, the moisture content of paddy grain was measured by using grain moisture meter. Similarly, grain detachment and rupture force of all collected samples were determined. After sun drying of each variety for 3 hours, the experimental procedure was repeated. The experiment for grain detachment force was carried out at four levels of moisture content (17.5±0.5, 16.5±0.5, 14.5±0.5 and 13.5±0.5%) and three levels of loading rate (50, 100, 150 mm/min) and for determining the rupture force, the experiment was carried out at same four levels of moisture content and three levels of loading rate (10, 15, 20 mm/min). The details of six varieties of paddy grains studied are presented in Table 1. The shape of grain attachment with pedicel at higher and lower grain moisture content was precisely observed by using a microscope and is shown in Fig. 4.

Fig. 1. Six varieties of paddy taken for study.

Fig. 2. Measurement of detachment force of grain by Universal Testing Machine.

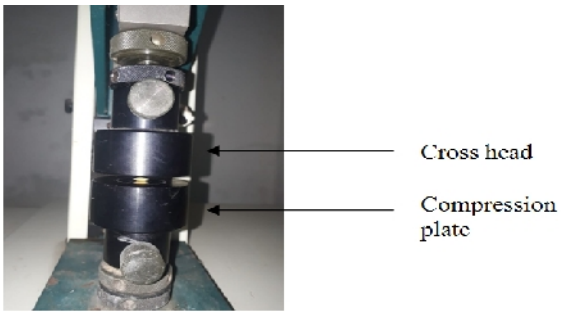


Fig. 3. Measurement of rupture force of grain by Universal Testing Machine.

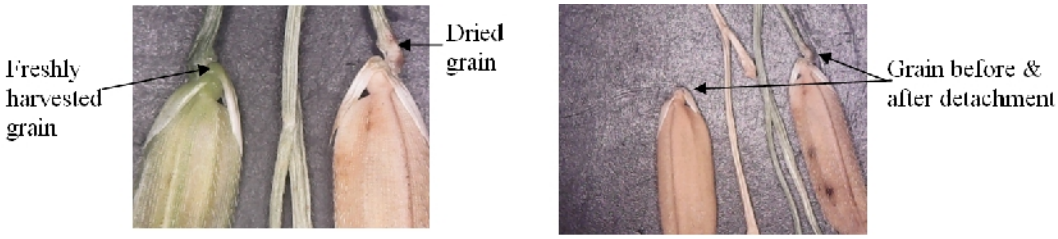


Fig. 4. Change of shape of pedicel joint with grain due to variation of moisture content.

Table 1: Agronomic characteristic of paddy varieties taken for study.

Type of grain	Variety	Duration, days	Length of panicle, cm	No. of grains per panicle	Length of grain, mm	Width of grain, mm
Long Grain	Lalat	135	24	101	9.66	2.66
	Pratibha	165	21	87	9.95	2.56
Medium Grain	Birupa	135	17	80	8.77	2.92
	Pratikshya	145	23	140	8.82	2.63
Short Grain	Sidhant	95	19	70	7.51	2.90
	Hasanta	145	22	130	7.96	2.99

RESULTS AND DISCUSSION

The grain detachment and rupture force of different varieties of paddy at four levels of grain moisture content and three levels of loading rate were measured. First, the grain detachment force of paddy grain from the lower portion of panicle was determined and averaged.

A. Grain detachment force of paddy grain

The detachment force of single grain of six paddy varieties Lalat, Pratibha, Birupa, Pratikshya, Sidhanta and Hasanta at different grain moisture content was measured at three levels of loading rate (50,100 and 150 mm/min) and the results are presented in Table 2.

Effect of moisture content on grain detachment force of paddy. For paddy variety Lalat (long grain), the detachment force decreased from 0.98 to 0.71 N as the moisture content decreased from 17.6 to 13.2% at loading rate 50 mm/min. Similarly, for loading rate 100 and 150 mm/min, the detachment force decreased from 0.93 to 0.68N and 0.90 to 0.63N as moisture content varied from 17.6 to 13.2% respectively.

. **Table 2: Detachment force (N) of paddy grain at various loading rate.**

Variety	Moisture content, %	Loading rate, mm/min		
		Detachment force, N		
		50	100	150
Lalat	17.6	0.98	0.93	0.90
	16.4	0.88	0.86	0.82
	14.4	0.79	0.72	0.68
	13.2	0.71	0.68	0.63
Pratibha	17.4	1.39	1.34	1.29
	16.1	1.28	1.25	1.19
	14.2	1.14	1.10	1.07
	13.0	0.97	0.91	0.86
Birupa	17.6	1.21	1.17	1.13
	16.3	1.14	1.09	1.03
	14.7	0.99	0.92	0.87
	13.8	0.91	0.85	0.79
Pratikshya	17.2	1.31	1.24	1.18
	16.2	1.23	1.17	1.11
	14.3	1.12	1.05	0.98
	13.4	1.04	0.92	0.83
Sidhanta	17.8	1.47	1.39	1.31
	16.7	1.35	1.28	1.20
	14.9	1.26	1.19	1.08
	13.6	1.11	1.00	0.92
Hasanta	17.7	1.13	1.05	0.97
	16.6	1.04	0.96	0.91
	14.5	0.95	0.89	0.79
	13.3	0.86	0.77	0.68

For paddy variety Pratikshya (medium grain), the grain detachment force decreased from 1.31 to 1.04, 1.24 to 0.92 and 1.18 to 0.83N as moisture content decreased from 17.2 to 13.4% when loading rate varied from 50 to 150 mm/min respectively. Similarly, for paddy variety Sidhanta (short grain), the grain detachment force varies from1.47 to 1.11N at 50 mm/min, 1.39 to 1.00N at 100 mm/min and 1.31 to 0.92N at 150 mm/min loading rate as moisture content decreased from 17.8 to 13.6% respectively (Fig. 5). Similarly, for all the varieties, the grain detachment force decreased significantly with decrease in moisture content at all the three levels of loading rate. This may be due to the reason that at higher moisture content the grain is attached with pedicel rigidly and this rigidity reduces with decrease in moisture content due to shrinkage of grain as seen in Fig. 4. This result is in agreement with the findings of Alizadeh and Allameh (2011) and Swain *et al*. (2020).

Effect of loading rate on grain detachment force of paddy. The effect of the loading rate on the grain detachment force was studied for six varieties of paddy, at three levels of loading rate 50, 100 and 150 mm/min. For paddy variety Lalat (long grain), the grain detachment force decreased from 0.98 to 0.90, 0.88 to 0.82, 0.79 to 0.68 and 0.71 to 0.63N at 17.6, 16.4, 14.4 and 13.2% moisture content when loading rate varied from 50 to 150 mm/min respectively. For paddy variety Birupa (medium grain), the grain detachment force decreased from 1.21 to 1.13, 1.14 to 1.03, 0.99 to 0.87 and 0.91 to 0.79N at 17.6, 16.3, 14.7 and 13.8% moisture content when loading rate varied from 50 to 150 mm/min respectively. Similarly, for paddy variety Sidhanta (short grain), the grain detachment force decreased from 1.47 to 1.31, 1.35 to 1.20, 1.26 to 1.08 and 1.11 to 0.92N at 17.8, 16.7, 14.9 and 13.6% moisture content when loading rate varied from 50 to 150 mm/min respectively. In general, it is seen that for all the varieties, the grain detachment force decreased significantly with the increase in loading rate from 50 to 150 mm/min at all four levels of grain moisture content (Fig. 6). This may be due to the reason that higher loading rate (speed) causes grain to detach easily at lower force.

The analysis of variance (ANOVA) of grain detachment force of different grain varieties is presented in Table 3. From table 3, it is seen that the variety, grain moisture content and loading rates have significant effect on detachment force of grain at both 1% and 5% level of significance. The interaction between variety and moisture content, variety and loading rate have significant effect on detachment force at both 1% and 5% level of significance whereas interaction between moisture content and loading rate the combined effort of variety, moisture content and loading rates and have significant effect on grain detachment force at 5% level of significance but not at 1% level of significance. It is also observed that there is significant difference in grain detachment force between levels of moisture content and loading rate.

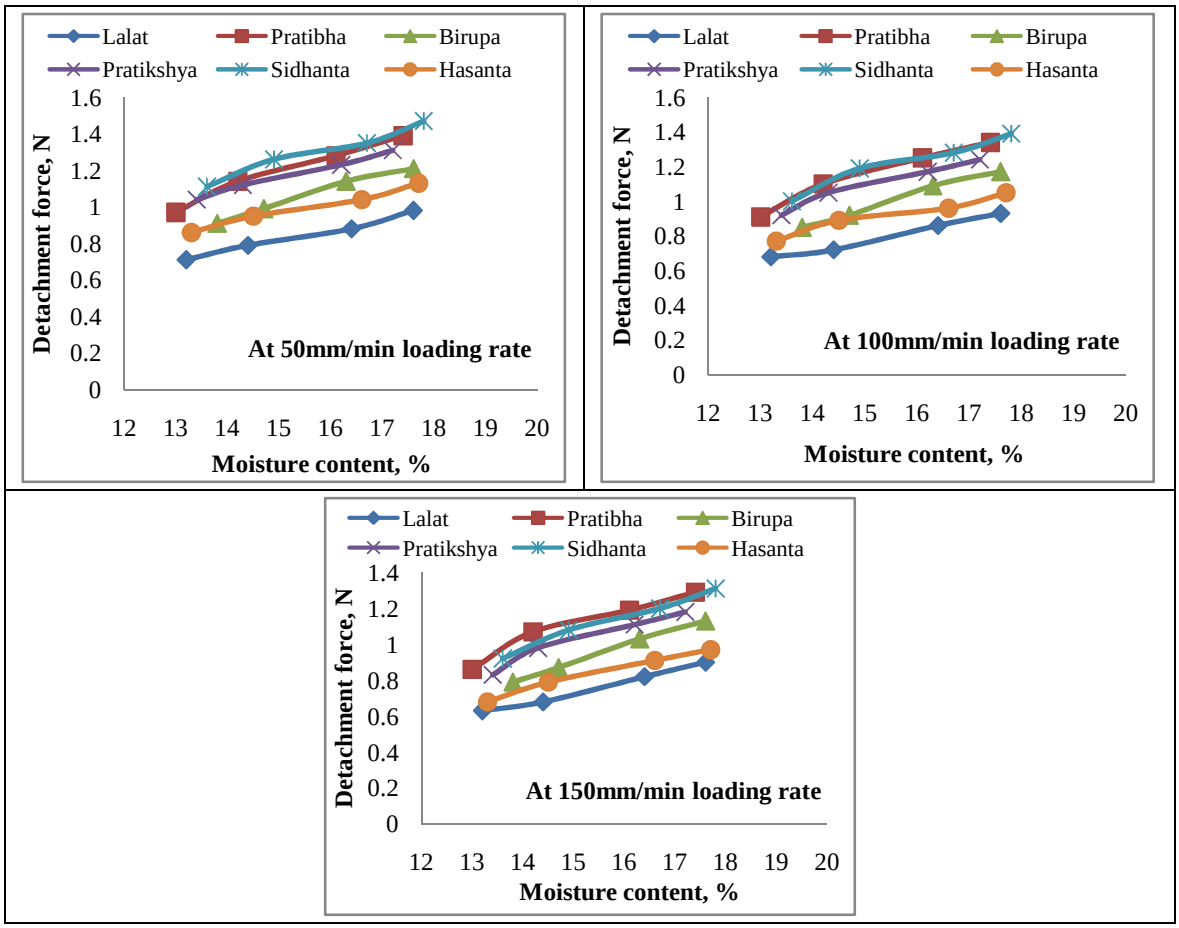
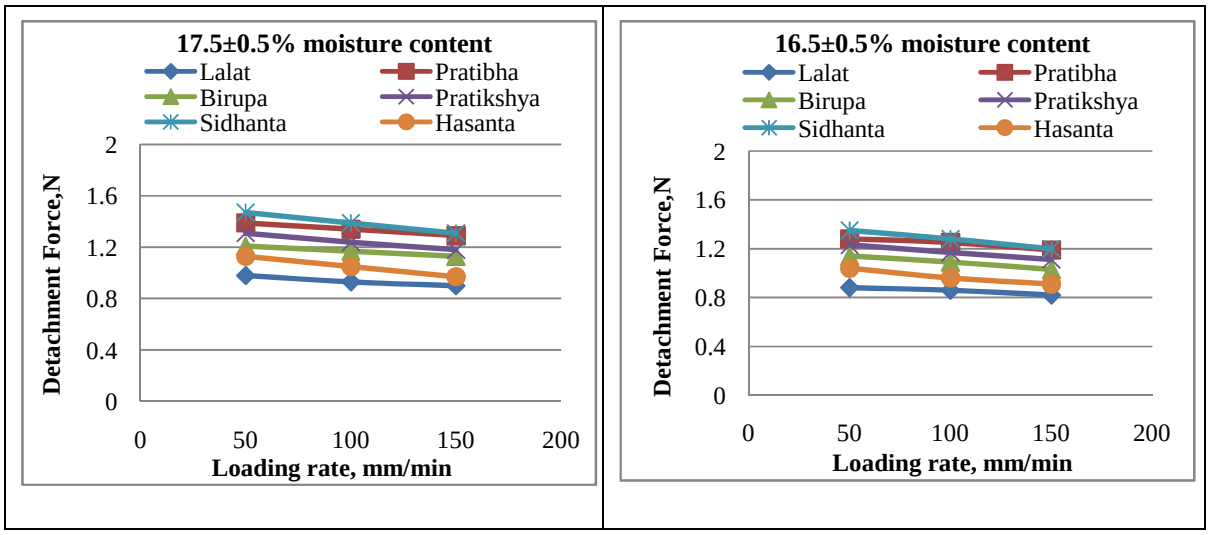


Fig. 5. Detachment force of single grain of different varieties at various moisture content.



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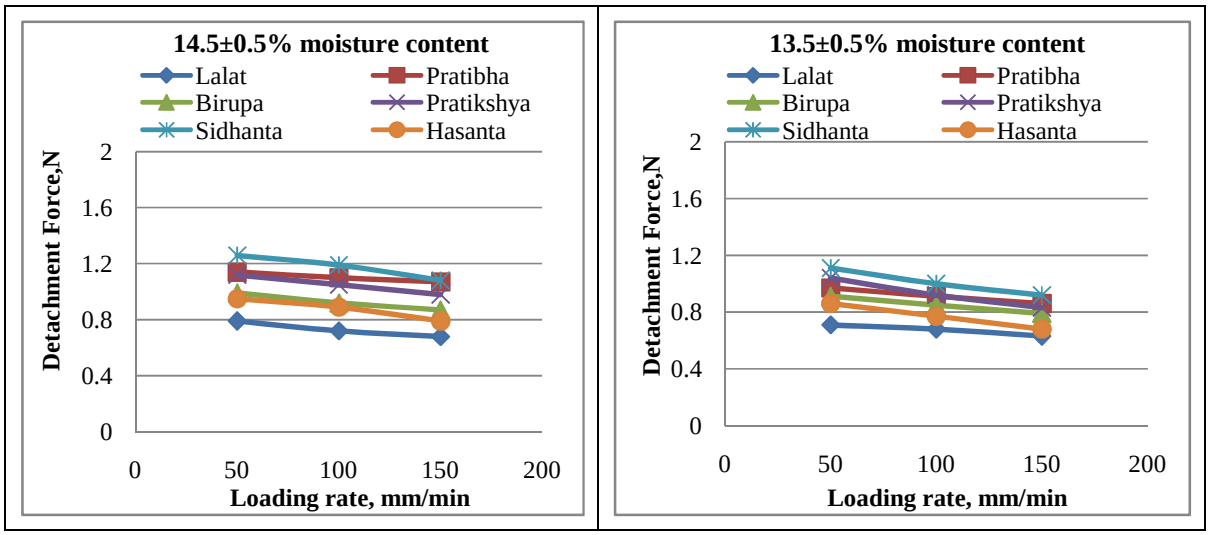

Fig. 6. Detachment force of single grain of different varieties at various loading rate.

Table 3: Analysis of variance of detachment force of single grain.

Source of variation	Degree of freedom	Sum of squares	Means of squares	Fcal	C.D	
					1%	5%
Variety	5	4.320	0.864	1657.4574	0.00992	0.007511
Grain moisture content	3	3.311	1.104	2117.1880	0.00809	0.006127
Variety × moisture content	15	0.110	0.007	14.0187	0.019839	0.015022
Loading rate	2	0.595	0.298	571.1427	0.007048	0.005337
Variety × loading rate	10	0.041	0.004	7.8900	0.017229	0.013045
Grain moisture content × loading rate	6	0.009	0.001	2.8114	0.014096	0.010674
Variety × grain moisture content × loading rate	30	0.016	0.001	0.9937	0.034457	0.026091
Error	144	0.075	0.001			
Total	215	8.477				

B. Rupture force of paddy grain

The rupture force of grains of six paddy varieties namely Lalat, Pratibha, Birupa, Pratikshya, Sidhanta and Hasanta at four levels of moisture content were measured at three levels of loading rate (10, 15, 20 mm/min) and the results are presented in Table 4.

Effect of moisture content on rupture force. For paddy variety Lalat (long grain), the rupture force increased from 116.8 to 156.7N at 10mm/min, 101.6 to 144.1N at 15mm/min and 88.2 to 121.8N at 20mm/min as themoisture content decreased from 17.6 to 13.2%. For paddy variety Birupa (medium grain), the rupture force increased from 18.6 to 167.5N at 10mm/min, 99.3 to 156.2N at 15mm/min and 86.2 to 141.4N at 20mm/min as the moisture content decreased from 17.6 to 13.8%.Similarly, for paddy variety Hasanta (short grain), the rupture force increased from 109.4 to 151.6, 97.9 to 140.5 and 85.4 to 129.8N as the moisture content decreased from 17.7 to 13.3% at same loading rate variation of 10 to 20 mm/min respectively. Similar trends were observed for all varieties of paddy grains at four levels of moisture content at three levels of loading rate (Fig. 7). It was observed that the rupture force increased significantly with decrease in grain moisture content. This may be due to the fact that at higher moisture content, the grain became softer and required less force while at lower moisture content, grain become harder and require higher force to rupture. Such behaviour can be related to higher cellular density that occurred with reduction of moisture content from the grain i.e. as number of cells per unit volume increased; it resulted in a greater resistance to compression at lower moisture contents. This conclusion is in agreement with the findings of Swain *et al.* (2020), Ribeiro *et al.* (2019) and Kotak *et al.* (2002).

Effect of loading rate on rupture force. The effect of loading rate on the rupture force of single grain was determined at three levels of loading rate of 10, 15 and 20 mm/min. For paddy variety Lalat (long grain), the rupture force decreased from 116.8 to 88.2, 128.9 to 97.6, 142.6 to 106.4 and 156.7 to 121.8N as loading rate increased from 10 to 20 mm/min at 17.6, 16.4, 14.4, 13.2% moisture content respectively.

Table 4: Rupture force (N) of paddy grain at various loading rate.

Variety	Moisture content, %	Loading rate, mm/min		
		Rupture force, N		
		10	15	20
Lalat	17.6	116.8	101.6	88.2
	16.4	128.9	112.9	97.6
	14.4	142.6	135.7	106.4
	13.2	156.7	144.1	121.8
Pratibha	17.4	123.2	115.4	101.9
	16.1	142.9	133.6	120.7
	14.2	169.5	145.8	137.0
	13.0	188.1	169.5	150.3
Birupa	17.6	108.6	99.3	86.2
	16.3	127.9	115.1	102.8
	14.7	148.2	133.7	126.3
	13.8	167.5	156.2	141.4
Pratikshya	17.2	132.4	121.9	107.8
	16.2	145.2	132.6	124.0
	14.3	183.3	168.2	151.1
	13.4	196.9	179.7	168.6
Sidhanta	17.8	134.0	120.1	109.3
	16.7	147.9	132.4	121.8
	14.9	157.3	145.6	133.9
	13.6	178.6	167.7	156.8
Hasanta	17.7	109.4	97.9	85.4
	16.6	121.3	111.4	101.9
	14.5	144.9	132.5	126.3
	13.3	151.6	140.5	129.8

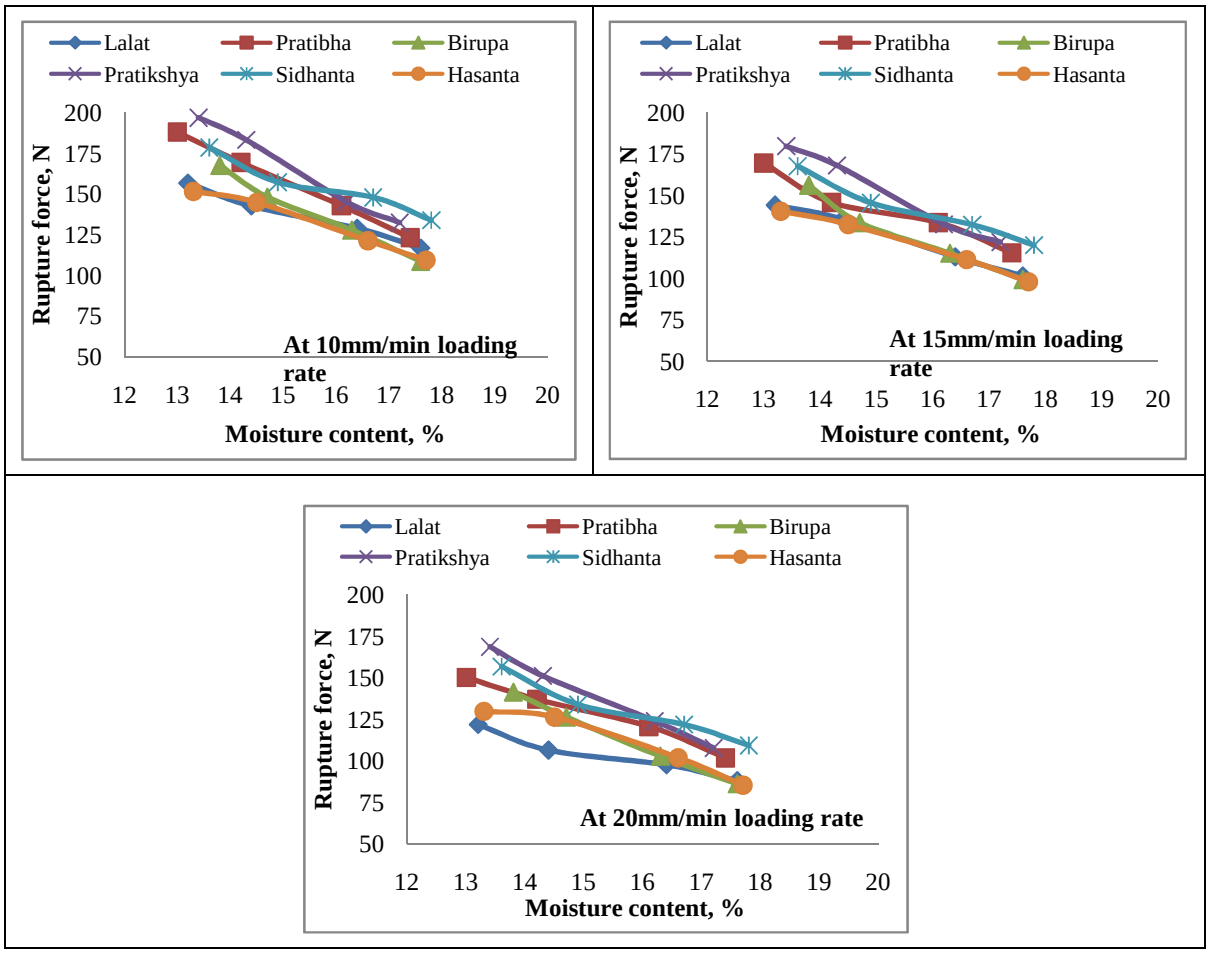

Fig. 7. Rupture force of grain of different varieties at various moisture content.

For paddy variety Birupa (medium grain), the rupture force decreased from 108.6 to 86.2, 127.9 to 102.8, 148.2 to 126.3 and 167.5 to 141.4N as loading rate increased from 10 to 20 mm/min at 17.6, 16.3, 14.7 and 13.8% moisture content. Similarly, for paddy variety Sidhanta (short grain), the rupture force decreased from 134.0 to 109.3, 147.9 to 121.8, 157.3 to 133.9 and 178.6 to 156.8N when loading rate varied from 10 to 20 mm/min at 17.8, 16.7, 14.9 and 13.6% moisture content respectively. Similar trends were also observed for all varieties of paddy grain at various moisture contents when loading rate increased (Fig. 8). It was observed that the rupture force decreased significantly with increase in loading rate at all four levels of moisture contents. This finding is consistent with the result presented by Tavakoli *et al.* (2009).

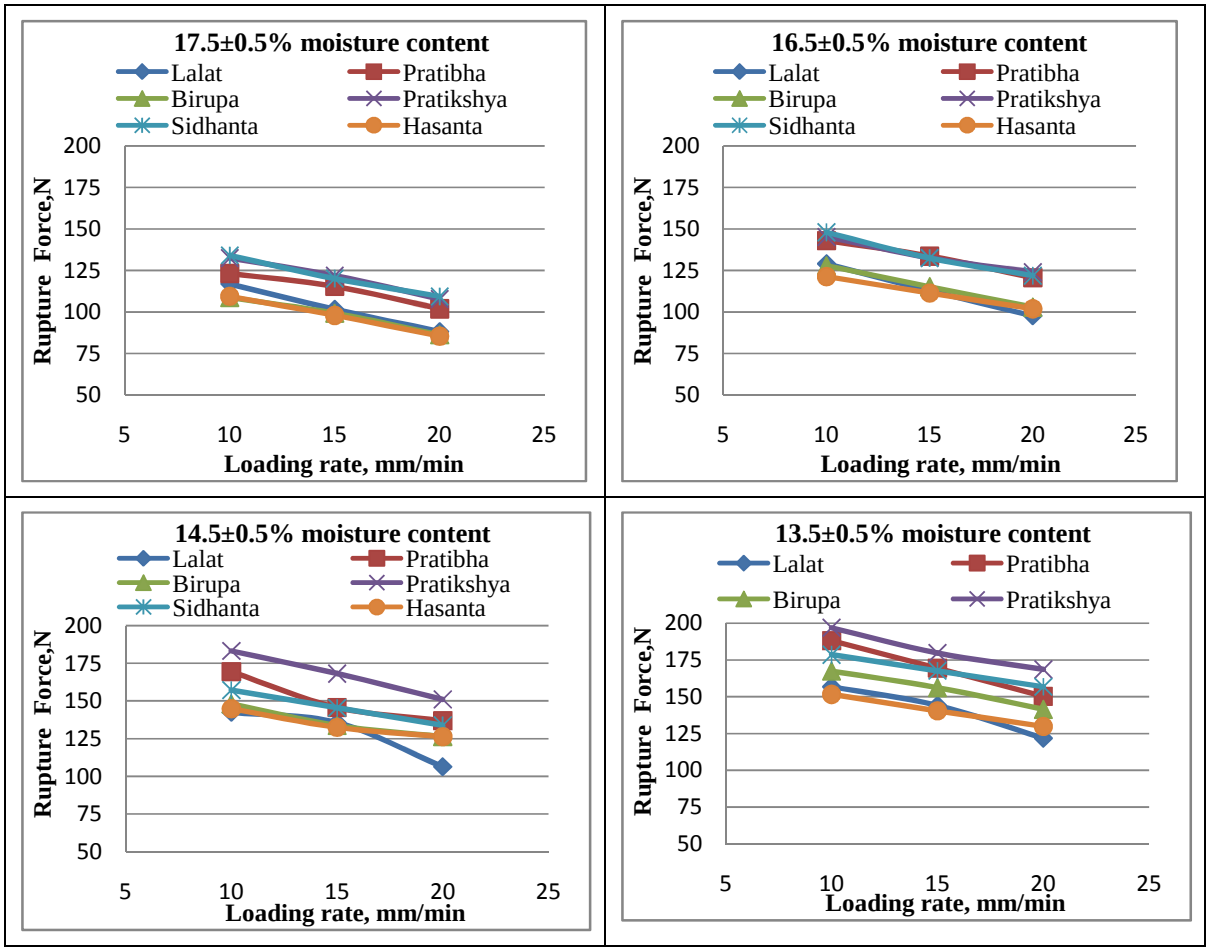

Fig. 8. Rupture force of single grain of different varieties at various loading rate.

Table 5: Analysis of variance of rupture force of single grain.

Source of variation	Degree of freedom	Sum of squares	Means of squares	F_{cal}	C.D	
					1%	5%
Variety	5	29453.254	5890.651	7201.2074	0.393388	0.29787
Grain moisture content	3	80163.028	26721.009	32665.9207	0.321341	0.243316
Variety × moisture content	15	3522.977	234.865	287.1181	0.787036	0.595937
Loading rate	2	24702.076	12351.038	15098.9067	0.278269	0.210703
Variety × loading rate	10	634.948	63.495	77.6212	0.681576	0.516084
Grain moisture content × loading rate	6	173.069	28.845	35.2622	0.556538	0.421406
Variety × grain moisture content × loading rate	30	835.074	27.836	34.0287	1.363152	1.032167
Error	144	117.793	0.818			
Total	215	139602				

The analysis of variance (ANOVA) of grain rupture force of different varieties is presented in Table 5. From Table 5, it is seen that the variety, grain moisture content and loading rates have significant effect on rupture strength of grain at 1% and 5% level of significance. The interaction between variety and moisture content, variety and loading rate, moisture content and loading rate have significant effect on rupture strength at both the levels of significance. Also, the combined effort of variety, moisture content and loading rates has significant effect on rupture strength of grain at both 1% and 5% level of significance. It is also observed that there is significant difference in rupture strength of grain between levels of moisture content and loading rate i.e. they are not at par with each other.

CONCLUSION

The grain detachment force from the panicles and rupture force of single grain of six popular varieties of paddy in the state were determined at four levels of grain moisture content varying from 13.0 to 17.8%by using UTM. The force required to detach the grains from panicle was measured at three levels of loading rate at 50, 100 and 150 mm/min while the grain rupture force for each variety was undertaken at three levels of loading rate of 10, 15 and 20 mm/min at same four levels of moisture content. The following conclusions were drawn from this study.

- Grain detachment force decreased significantly with decrease in grain moisture content for all the six varieties namely Lalat, Pratibha, Birupa, Pratikshya, Sidhanta and Hasantaat all four levels of grain moisture content.
- The maximum detachment force(1.47N) of single grain obtained for Sidhanta variety at higher grain moisture content of 17.8% at lowest loading rate of 50mm/min, while the minimum force (0.63N) required for Lalat variety at higher loading rate of 150 mm/min at lowest moisture content of 13.2%.
- The rupture force decreased significantly as the grain moisture content and loading rate increased.
- The maximum rupture force (196.9 N) obtained for Pratikshya variety at lowest moisture content of 13.4% at lowest loading rate of 10mm/min while the minimum force (85.4N) required for Hasanta variety at higher loading rate of 20 mm/min at highest moisture content of 17.7%.

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