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Research Paper

Process optimization of rice milling for paddy varieties of Kashmir valley

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ABSTRACT

Physical characteristics and moisture content of local paddy varieties (K-39, Nik china and Jhelum) was measured and operational parameters of rice sheller and polisher were optimized for high yield of head rice. Tri-axial dimensions revealed an average eccentricity index of 1.5, 1.58 and 1.64 conforming bold shape of K-39, Nik China and Jhelum as per ISO classification. The average thickness was 1.60 mm, 1.58 mm and 1.5 mm for K-39, Nik China and Jhelum. The maximum milling efficiency of 86.8% was associated with Jhelum variety with 30% head (brown) rice recovery at sheller clearance of 2.5 mm and 12.3% moisture content. The polishing efficiency varied from 82.9 – 99.4 %, with maximum value related to K-39 variety at 2.0 mm sheller clearance and polisher residence time of 30 seconds. Maximum milling yield of 90.4% was obtained with Jhelum at 2.5 mm sheller clearance and 60 seconds polisher residence time. The degree of milling was maximum with K-39 at 2.0 mm sheller clearance and polisher residence time of 90 seconds. The study can be useful for industrial units and custom based centres to reduce unit cost of rice milling.

Key words: Degree of milling, milling, paddy, polisher, processing, sheller

Rice (*Oryza sativa* L.) is staple food crop fulfilling the dietary requirement of more than 3 billion people (FAOSTAT, 2017) with an acreage of 165 million hectares producing 740.95 million tonnes annually (FAO, 2014, Binod *et al.,* 2010). India accounts 20% of the global production with 152.50 million tonnes (Muzamil *et al.,* 2020). Jammu and Kashmir produces 5816 ('000 Qtls.) from 267.58 ('000 hectares) (Digest of Statistics, 2021). Rice belongs to the genus Oryza, within the broad Gramineae family comprising of 24 species, including 22 wild and 2 cultivable (*Oryza sativa* and *Oryza glaberrima*) species. The physical composition of rice possesses two distinct parts *i.e.* outer protective covering known as husk or hull and the palatable rice caryopsis or fruit. The composition includes 69% starch laded endosperm, 20% rice husk and 11% rice bran (Dhankhar, 2014). In terms of composition, rice contains carbon, ash and volatile compounds to the tune of 15%, 18% and 67%, respectively (Lim *et al*., 2012).

Milling process transforms the raw paddy into consumable head rice. The value of the harvested rice is measured in terms of milling yield and head rice percentage (Kim and Lee, 2012). The process involves the removal of husk and bran layer from the paddy to improve its nutritional content and sensory characteristics (Dhankhar, 2014). The milling can either be single-stage or double-stage process (Odior and Oyawale, 2011). The single-stage process achieves the objective of the removal of husk and bran layer in one-go, usually with high damage percentage. Double-stage process involves the extraction of husk and bran layer individually, either in single machine or different machines. It is widely believed that the milling yield is comparatively higher in double-stage process than single-stage process (International Rice Research Institute, 2016). The by-products of the rice milling – brokens, husk and bran layer are used in industries and bioactive product formulations (Rohman *et al.,* 2014). Typically, the broken percentage in rice milling should not exceed 15% (Chen *et al.*, 1997).

The husk is removed by rice sheller, which is an essential source of seed antioxidant (Kim *et al*., 2012), fuel (Sikarwar *et al.,* 2016), power generation (Pradhan *et al.,* 2013), steam production for parboiling of rice (Roy *et al.,* 2006), soil fertilizer (Kumar *et al.,* 2013) and poultry feed. The bran layer from the shelled rice is extracted by means of rice polisher. The polished rice is graded on the basis of size and rice kernels less than three-fourth of the kernel length is considered as brokens (Van Dalen, 2004). Bran layer is used as anti-cancer agent (Ling-Tan and Norhaizan, 2017) and preparation of low-fat, high-fiber products (Sharif *et al.,* 2014). The brokens are used as food additives (Kim *et al.,* 2012), baby food (Gujaral and Rosell, 2004) and beer brewing (Marconi *et al.,* 2017) as it is rich in carbohydrates (34-52%), lipids (15-22%), fiber (7-11%), ash (6-10%), protein (10-16%) and moisture (8-12%) (Luh, 1991).

Milling procedure is influenced by the environmental parameters, milling processes, drying and genotype. Environmental parameters like temperature, air moisture and relative humidity and milling processes like type of mill, cylinder speed, duration, grain moisture content plays a dominant role in the milling yield (Schluterman and Siebenmorgen, 2007). The paddy is usually dried to extract the moisture from the inner layers and lower down to 12-13% (wb) for milling. The drying process is critical as the variations in temperature and moisture inside the kernel induce stresses that ultimately results in the fissure on the upper surface (Siebenmorgen *et al.,* 2005). The fissures on the surface are prone to damage and results in breakage, thereby, affecting the cooking parameters (qualitatively) and market value (financially) (Zhang *et al.,* 2005).

MATERIALS AND METHODS

Market Survey: A market survey was conducted to assess the percentage share of paddy varieties cultivated in various districts of Kashmir valley. The survey revealed that three varieties viz. K-39, Nik china and Jhelum are occupying maximum share at the local market.

Collection and preparation of Paddy Varieties: Three varieties viz. K-39, Nik china and Jhelum were procured from farmers through the Agro-processing Lab of College of Agricultural Engineering and Technology and seed processing unit at SKUAST-K, Shalimar. A total of 100 kg of paddy was used for experimentation apart from the quantity used for preliminary experiments to select the appropriate clearance in rice sheller and residence time in polisher. The physical characteristics of each variety were measured using digital Vernier Calliper with a least count of 0.01 mm accuracy. The measurements were made after cleaning, grading and passing the samples of each variety through sampler for random distribution.

Experimental Equipment's: A rice sheller was used to remove the upper husk of the paddy varieties. It was rubber roll type and powered by 0.5 hp electric motor rotating at 1425 rpm with a capacity of 400 grams per batch, Table 1. The study also demanded the utilization of a rice polisher with 540 x 380 x390 mm, 150-gram capacity operated by 0.5 hp electric motor containing Emery roll abrasive wheel of 150 mm diameter, Fig. 1.

Table 1: Equipment's used for the study

S. No.	Name of the equipment	Parameters	Values
1.	Rice Sheller	Capacity, grams	400
		Size, mm	1000 x 780 x 820
		Electric motor, hp	0.5
		RPM	1425
		Rubber roll, mm	200 x 75
		Type	Friction type
2.	Rice Polisher	Capacity, grams	150
		Size, mm	540 x 380 x390
		Weight, kg	48
		Abrasive wheel, mm	150 x 40
		Electric motor, hp	0.5
		RPM	1425
		Emery roll abrasive wheel diameter, mm	150

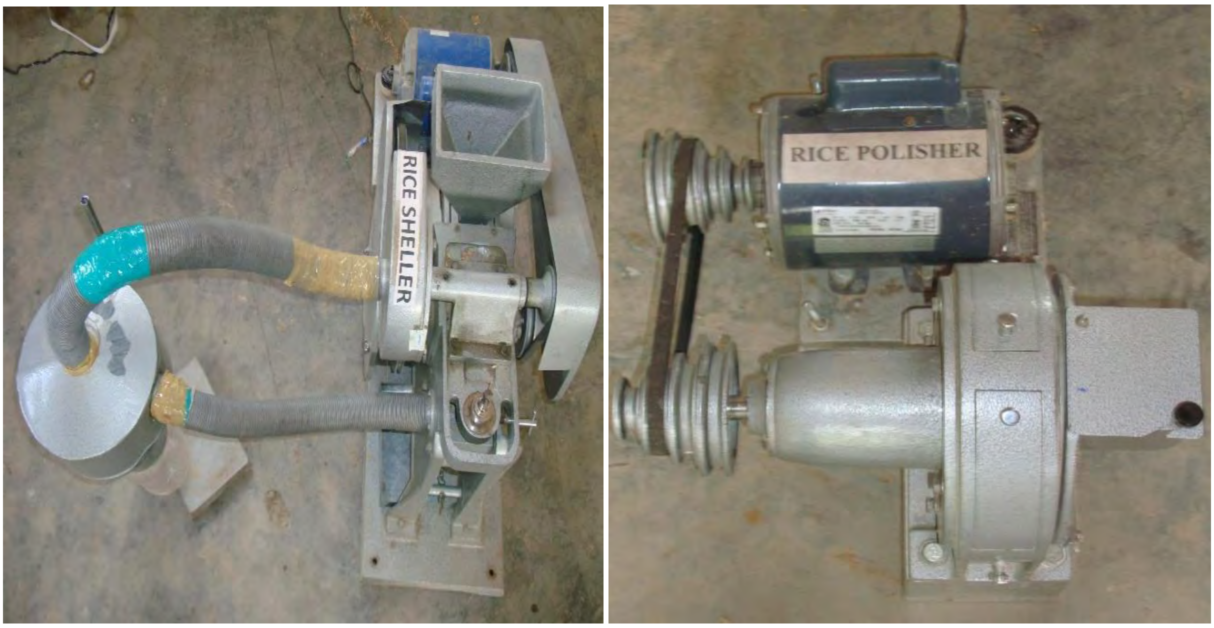

Fig. 1: Rice sheller and polisher used for the study

Plan of experiment: The experiments were laid as per the plan of experiment with three varieties (K-39, Nik china and Jhelum), clearance of the rolls in sheller (1.5 mm, 2.0 mm and 2.5 mm) and residence time of polisher (30, 60 and 90 seconds), Table 2. The variables and levels were selected on the basis of preliminary experiments conducted and literature cited. The responses were measured in terms of milling efficiency, head rice yield after milling, polishing efficiency, head rice yield after polishing, percent broken's degree of milling and milling yield.

Table 2: Plan of experiment for the optimization of operational parameters

S. No.	Variables	Levels	Response
1.	Variety	3 (K-39, Nik China and Jhelum)	• Milling efficiency • Head rice yield after milling, % • Polishing efficiency • Head rice yield after polishing, % • Percent brokens • Degree of milling • Milling yield
2.	Clearance, mm	3 (1.5 mm, 2.0 mm and 2.5 mm)	
3.	Polishing Time, s	3 (30 s, 60 s and 90 s)	

Unit operations involved in processing of paddy:

Procurement: The paddy varieties procured from various districts of J&K, through the Agro-Processing Lab of College of Agricultural Engineering and Technology, SKUAST-K and seed processing unit at SKUAST-K, Shalimar were of good quality and free from contaminants.

Cleaning: The raw paddy procured was subjected to cleaning to remove the foreign materials such as stones, stalk, dust, soil particles and weed seeds. The cleaning was carried out through a set of sieves and manually.

Milling: The paddy was allowed to pass through paddy sheller with a set of rubber rollers and corrugated metallic roller rotating in opposite direction with different velocities. The shear force generated by the differential speed pulled off the husk layer from the upper surface of the paddy. The husk was collected in the polypet Jar of sheller placed under the cyclone separator. However, some husk remained adhered on the paddy was removed manually before feeding the sample to the polishing unit.

Sampling: The output from the sheller was obtained in terms of head rice and broken's. The output was passed through the sample divider 3-4 times to mix the components uniformly for the determination of milling efficiency and head rice yield percentage.

Polishing: The brown rice (head rice) was fed to the polisher for removing the bran layer adhered to the rice kernels. At this stage, maximum mechanical and thermal stresses were applied, making the rice kernels susceptible to damage (breakage). The samples were kept in the polisher for a specified duration to segregate polished rice and bran. The polished rice was collected in the rice collecting cup and bran in the collecting drawer of the rice polisher.

Grading: The process of milling (polishing) led to formation of broken kernels. Therefore, these brokens were removed from whole rice kernels by using the sieves or manually at the end of milling process to determine the extent of polished rice produced by the polisher, Fig. 2.

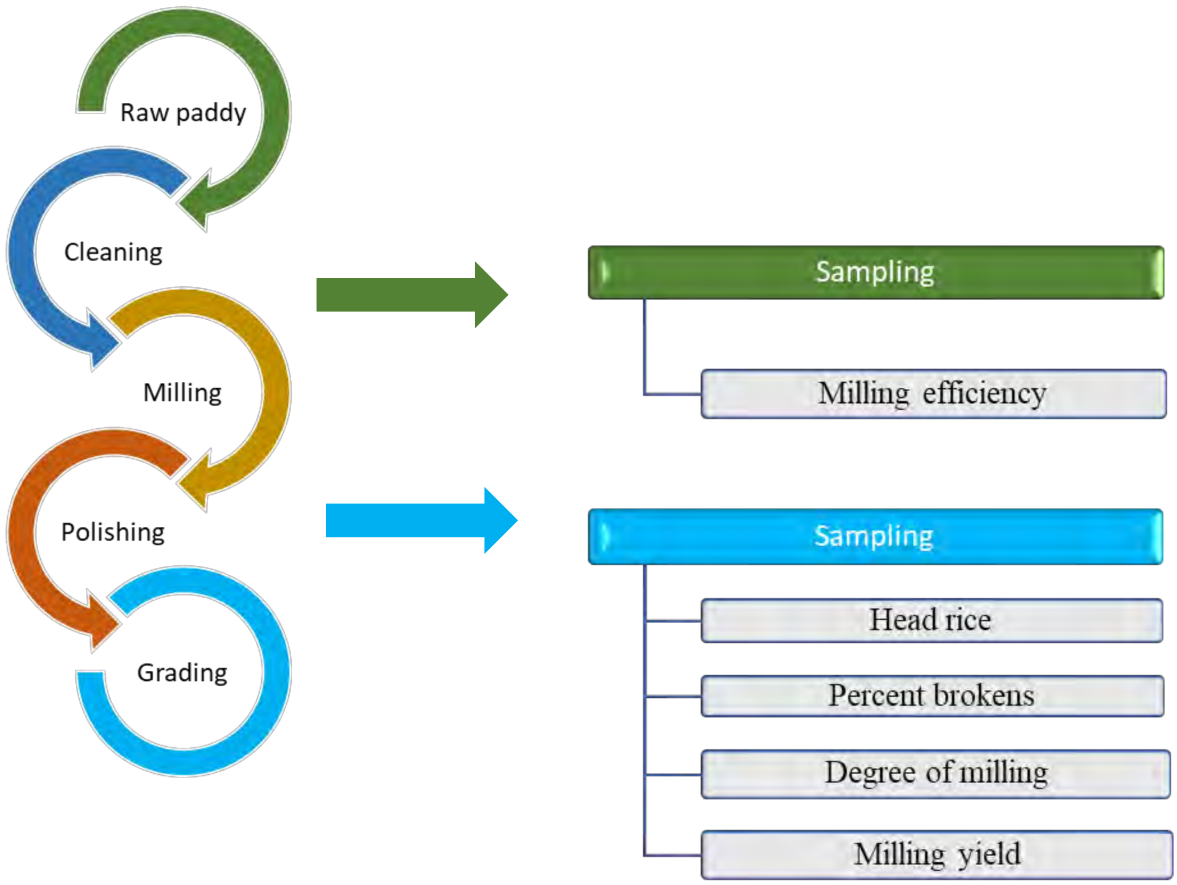

Fig. 2: Process Flow Diagram of rice milling

Statistical analysis: The statistical analysis for the test of significance was carried out using the software MINITAB (Faisal et al., 2018). A full factorial design was used to test significance of means at 5% level of significance. It was also used to assess the interaction between different parameters to ascertain their significance on the measured response parameters.

Performance evaluation parameters: The response parameters of milling were measured in a sequential order to assess the impact of operational parameters on the milling quality.

Moisture Content: Moisture content was measured by standard gravimetric method. About 5 g of grains were placed in oven at 105 °C for 24 h and the variation in the weight was expressed in percent wet basis (Mohiuddin *et al*., 2022). The moisture content was also verified using moisture meter.

$$\text{Moisture Content, \%} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \text{ ----------------------- (1)}$$

Physical Dimensions of Grain: The physical characteristics are essential for the operational characteristics of the agricultural machinery (Muzamil *et al.,* 2020). The shape and size of the grain is a varietal property. The grain dimensions provide an idea about the type of the machinery or process required for milling. About 100 paddy grain samples were selected at random from each replicate to calculate dimensions like length to width ratio, sphericity using a Vernier Calliper. The length to width ratio is also termed as eccentricity (Mohiuddin *et al*., 2022).

$$Eccentricity\ index = \frac{Average\ paddy\ length, mm}{Average\ paddy\ width, mm} \text{ ---------------------------- (2)}$$

$$Sphericity = \frac{(l \times b \times t)^{\frac{1}{3}}}{l} \text{ -- (3)}$$

Milling Efficiency: The paddy undergoes shearing action between the two rolls by virtue of which the husk portion was sheared off and collected in the polypet jar under cyclone separator of the sheller.

$$Milling\ efficiency, \% = \frac{Output\ brown\ rice}{Input\ paddy\ fed} \times 100 \text{ ------------------------ (4)}$$

Polishing Efficiency: The output produced in the collecting trough of the polisher to the input brown rice fed is termed as polishing efficiency of the polisher.

$$\text{Polishing Efficiency , \%} = \frac{\text{Wt. of Polished rice}}{\text{Wt. of brown rice}} \times 100 \text{ ------------------ (5)}$$

Head Rice Yield: It is the weight percentage of head rice or kernels (excluding brokens) obtained from a sample of paddy (Gujral *et al.,* 2002). Head rice normally includes broken kernels that are 75-80% of the whole kernel length. It is the most important criteria to judge the performance of milled rice quality.

$$Head\ Rice\ yield, \% = \frac{Wt.\ of\ Head\ rice}{Wt.\ of\ milled\ rice} \times 100 \text{ ---------------------- (6)}$$

Percent Brokens: Percent Brokens involves the amount of rice that is broken during milling and polishing of rice. The broken grains were separated from the whole grains manually to determine the percentage of brokens.

$$Broken\ rice, \% = \frac{Wt. of\ broken\ rice}{Wt.\ of\ milled\ rice} \times 100 \text{ ---------------------------- (7)}$$

Degree of Milling: The degree of milling refers to the extraction percentage of bran from the outer layers of shelled grains. The degree of milling influences the acceptance of the customers. It also influences the colour and cooking behaviour of rice (Gujral *et al.,* 2002)

$$Degree\ of\ milling\ , \% = \frac{Weight\ of\ bran}{Weight\ of\ brown\ rice} \times 100 \text{ ------------- (8)}$$

Milling Yield: It is the total milled rice percentage expressed as weight percentage of polished rice (including brokens) from a sample of brown rice. The milling yield is the main parameter depicting the rice milling process.

$$Milling\ Yield\ ,\ \% = \frac{Weight\ of\ Polished\ rice}{Weight\ of\ brown\ rice}\ x\ 100 \text{ ------------------ (9)}$$

RESULTS AND DISCUSSION

Attributes of selected paddy varieties:

Moisture content: The moisture content of the three varieties was measured before milling operation. It was observed that the moisture content was within the recommended levels (Kim and Lee, 2012) for milling operation of the selected paddy varieties, Table 3.

Table 3: Moisture content of paddy varieties

S. No.	Variety	Moisture Content (% wb)	
		Gravimetric method	Digital Moisture Meter
1.	K-39	11.8	11.7
2.	Nik China	12.2	12.2
3.	Jhelum	12.3	12.1

(*Each value indicates an average of 10 replications)

Physical characteristics of paddy varieties: The physical characteristics of the paddy varieties were measured with digital Vernier Calliper. It was observed that the average length, width and thickness was 3.7 mm, 2.19 mm and 1.41 mm for Jhelum, 3.66 mm, 2.31 mm and 1.58 mm for Nik China and 3.52 mm, 2.35 mm and 1.6 mm for K – 39 variety, Table 4. The average sphericity was 0.61, 0.64 and 0.67 for Jhelum, Nik china and K-39.

The dimensions were essential to select the clearance of rubber roll sheller and polisher for higher milling yield. The length to width ratio was 1.64, 1.58 and 1.5 for Jhelum, Nik china and K-39. As per ISO classification (Table 5), the shape corresponds to bold for all the three paddy varieties.

Variation in milling efficiency, head rice recovery and broken percentage: The milling process involves the removal of upper husk from the paddy. In the case of Jhelum, the milling efficiency ranged from 80 to 86.8 % with highest milling efficiency of 86.8 % occurred at a clearance of 2.5 mm and lowest milling Efficiency 80 % at 2.0 mm clearance, Table 6.

For K-39, milling efficiency varied from 82.4 to 85.9 %, comparatively lower than the Jhelum variety. In case of Nik China, milling efficiency of 84.8 % was related to 2.0 mm clearance. As the milling commences, rubber rolls of the sheller worn out, resulting in an increased gap between them. The gap needs to be adjusted periodically for achieving optimum milling efficiency.

The statistical analysis revealed that both variety and clearance were significantly influencing the milling efficiency at 5% level of significance.

In case of Jhelum, highest head rice recovery (HRR) of 70%, broken percentage (BP) of 30% occurred at 2.5 mm clearance and lowest 64%, broken percentage of 35% at 1.5 mm clearance, Fig. 3. In case of Nik China, maximum HRR was 72.5 % and BP 27.5 % with 2.5 mm clearance and minimum HRR of 64 % and BP 36% at 1.5 mm clearance, respectively.

A similar trend was observed with K-39 with HRR of 78 %, BP 22% at 2.0 mm and lowest HRR of 75 %, BP 25% at 1.5 mm clearance. The results showed the significance ($p<0.05$) of variety and clearance on the head rice yield percentage.

Table 4: Physical characteristics of different varieties of paddy endemic to Kashmir valley

K – 39					Nik China					Jhelum				
Length, mm	Width, mm	Thickness, mm	L/W ratio	Sphericity	Length, mm	Width, mm	Thickness, mm	L/W ratio	Sphericity	Length, mm	Width, mm	Thickness, mm	L/W ratio	Sphericity
3.60	2.41	1.73	1.49	0.68	3.42	2.41	1.73	1.41	0.70	3.04	2.21	1.55	1.37	0.71
3.54	2.34	1.67	1.51	0.67	4.0	2.24	1.53	1.78	0.59	3.34	2.19	1.47	1.52	0.66
3.0	2.31	1.53	1.29	0.73	3.57	2.35	1.60	1.51	0.66	3.64	2.14	1.47	1.70	0.61
3.51	2.34	1.71	1.50	0.68	3.97	2.21	1.54	1.79	0.59	3.54	2.24	1.53	1.58	0.64
3.63	2.40	1.58	1.51	0.66	3.61	2.31	1.53	1.56	0.64	3.97	2.11	1.34	1.88	0.56
3.51	2.34	1.56	1.50	0.66	3.50	2.31	1.73	1.51	0.68	3.87	2.21	1.47	1.75	0.60
3.79	2.41	1.77	1.57	0.66	3.34	2.41	1.59	1.38	0.70	3.71	2.20	1.47	1.68	0.61
3.65	2.37	1.56	1.54	0.65	3.87	2.31	1.44	1.67	0.60	3.92	2.30	1.23	1.70	0.56
3.43	2.12	1.33	1.61	0.62	3.55	2.36	1.79	1.50	0.69	3.54	2.19	1.31	1.61	0.61
3.55	2.53	1.61	1.40	0.68	3.81	2.22	1.36	1.71	0.59	3.51	2.13	1.34	1.64	0.61
3.52	**2.35**	**1.60**	**1.5**	**0.67**	**3.66**	**2.31**	**1.58**	**1.58**	**0.64**	**3.70**	**2.19**	**1.41**	**1.64**	**0.61**

Table 5: Shape classification table according to eccentricity index (ISO Classification)

Scale	Shape	L/W
9	Round	1.0 or less
5	Bold	1.1 – 2.0
3	Medium	2.1 – 3.0
1	Slender	Over 3

Table 6: Variation in milling efficiency with paddy variety and clearance

Variety	Clearance, (mm)	After milling with Rubber Roll Sheller		Milling efficiency (%)
		Wt. of Brown Rice, kg	*Wt. of Husk, kg (mechanical + manual separation) (kg)*	
Jhelum	1.5	1.86	0.47+0.17	81.2
Jhelum	2.0	1.89	0.50+0.11	80.0
Jhelum	2.5	1.97	0.33+0.20	86.8
K-39	1.5	1.90	0.35+0.16	82.4
K-39	2.0	1.98	0.32+0.16	85.9
K-39	2.5	1.85	0.24+0.21	82.6
Nik china	1.5	1.95	0.382+0.1	84.0
Nik china	2.0	1.98	0.33+0.14	84.8
Nik china	2.5	1.83	0.43+0.13	78.4

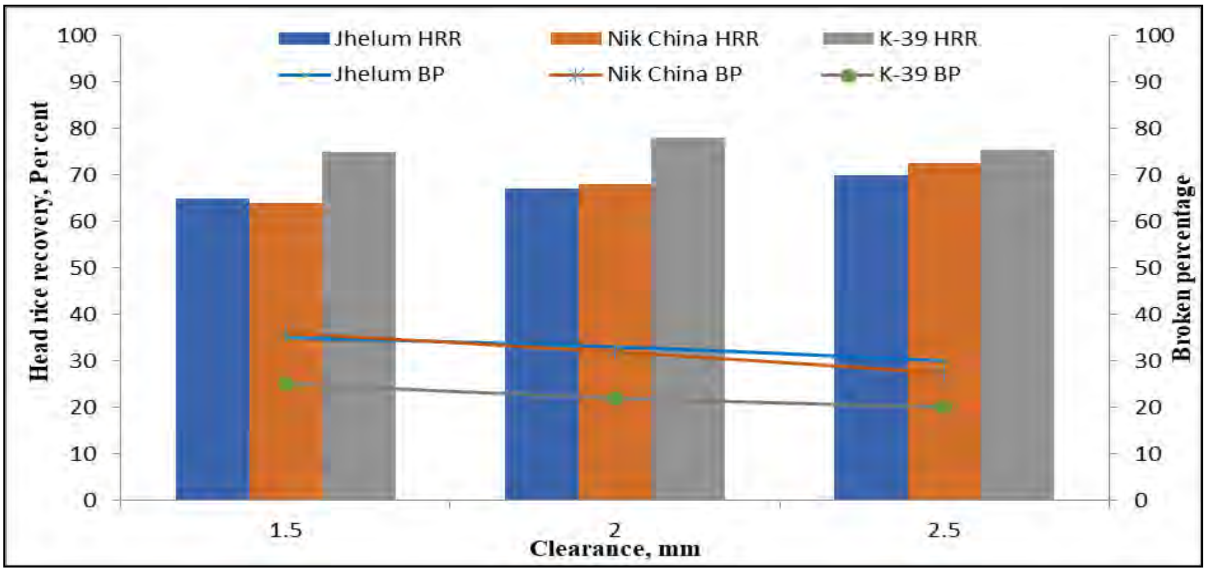

Fig. 3: Variation in head rice recovery and broken percentage after shelling for selected paddy varieties

Variation in polishing efficiency, head rice recovery and broken percentage: The polishing efficiency ranged from 85.4 to 99.0 % in case of Jhelum, 99.0% associated with 1.5 mm sheller clearance and 30 seconds polisher residence time and lowest 85.4 % with sheller clearance of 1.5 mm and residence time of 90 s, Fig. 4. Similarly, in case of Nik china, the highest value of 98 % was related with 1.5 mm clearance and polishing time of 30 seconds. In case of K-39, the polishing efficiency varied from 84 to 99.4 % at different polisher residence time, respectively. It was observed that polishing efficiency decreased with an increase in residence time for the same sheller clearance. This might be due to more extraction of bran layers from the brown rice at long intervals. Moreover, the overheated components caused the moisture to adhere with the rice kernels which also results in decreased efficiency of polisher at high residence time. The analysis showed that residence time had significant effect on polishing efficiency at 5 % level of significance.

The head rice recovery (HRR) and broken percentage (BP) after polishing is an efficient parameter to judge the efficiency of the rice polisher. The HRR and BP of Jhelum variety varied from 20–54 % and 46-80 %, respectively. The highest 54 % was observed with sheller clearance of 2.0 mm and polishing time of 30 s. The corresponding BP was 48 per cent, Fig. 5. In case of Nik china, it changed from 38-59 %, maximum 59 % HRR was found to be linked with 2.0 mm sheller clearance and polishing time of 30 seconds. K-39 with maximum HRR 65% occurred at a clearance of 2.0 mm and polishing time of 30 s while lowest at clearance of 2.0 mm and polishing time of 90 seconds, respectively. It was observed that high residence time provided more grinding of rice kernels and more broken percentage. The analysis revealed that variety, clearance and polishing time had significant effect on head rice recovery at 5 % level of significance

Fig. 4: Change in polishing efficiency of paddy varieties

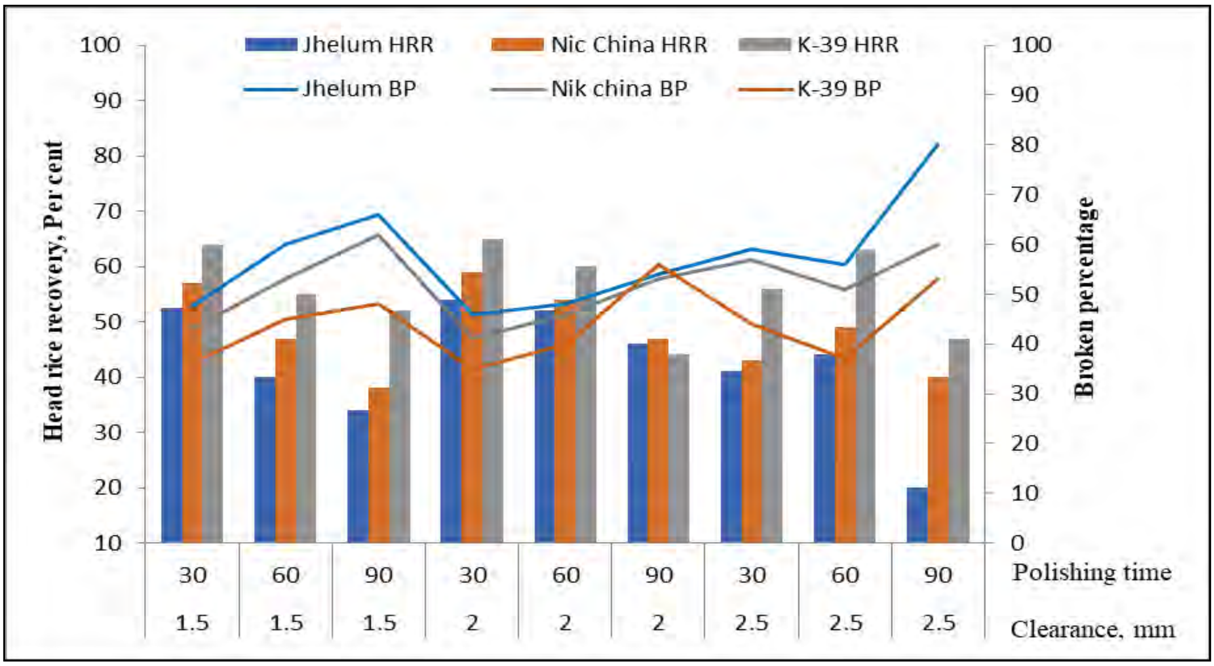

Fig. 5: Variation in head rice recovery (HRR) and broken percentage (BP) after polishing

Effect of process variables on degree of milling (DOM) and milling yield (MY): The degree of milling varied from 8.4 to 16.8 % for Jhelum, 7.8 to 17.2 % for Nik china and 6.6 to 18.8 % for K-39, Fig. 6. In case of Jhelum, maximum value of DOM 16.8 % was associated with sheller clearance of 1.5 mm, 90 s and 2.5 mm, 90 seconds and lowest 8.4 % at 2.5 mm clearance and 60 s residence time. In case of Nik China, highest DOM of 17.2 % was observed for a clearance of 2.5 mm, 90 s polishing time and minimum value of 7.8 % was observed for 2.5 mm and 60 seconds, respectively. The variety K-39 with DOM of 18.8 % occurred at 2.0 mm and 90 s residence time.

The outcome of the milling process is expressed in terms of milling yield. It was observed that the milling yield varied from 73.4-90.4 % for Jhelum, 71-90 % for Nik china and 64.4-85.4 % for K-39 variety, Fig. 6. For Jhelum, the highest milling yield of 90.4% occurred at sheller clearance of 2.5 mm and 30 s residence time. Nik china witnessed the highest milling yield of 90% 1.5 mm and 30 s and lowest 71% at 2.5 mm and 90 s, respectively. K-39 variety with maximum milling yield of 85.4 % was observed at 2.0 mm and 60 s polisher residence time. The analysis of the data revealed the significance ($p<0.05$) of the process parameters on the degree of milling and milling yield.

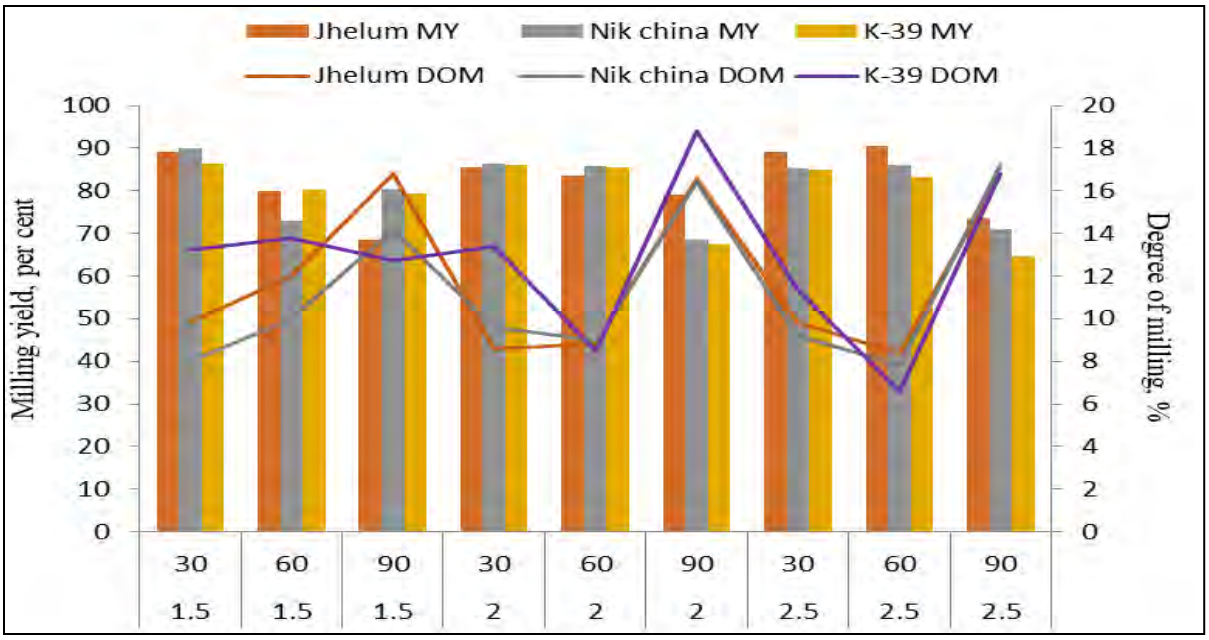

Fig. 6: Variation in degree of milling (DOM) and milling yield (MY)

CONCLUSION

The study resulted in the optimization of parameters for the paddy varieties endemic to the region of Kashmir valley. The process parameters of the rice sheller (2.5 mm clearance) and polisher (60 s residence time) resulted in milling efficiency of 86.8 %, HRR after milling 70 %, polishing efficiency 98.8 %, HRR after polishing 44%, DOM 8.4 % and milling yield of 90.4 % for Jhelum variety. For Nik China, the milling efficiency of 85.9%, HRR after milling 72.5 %, polishing efficiency 94.4 %, HRR after polishing 43%, DOM 9.2 % and milling yield 85.2 % at sheller clearance of 2.5 mm and 30 s residence time. In case of K-39 variety, the milling efficiency 84.8 %, HRR after milling 75.5 %, polishing efficiency 96.4 %, HRR after polishing 56%, DOM 11.4 % and milling yield 85.0 %, respectively. The study can be beneficial for rice processing mills and dealers to reduce the overall cost of paddy processing.

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