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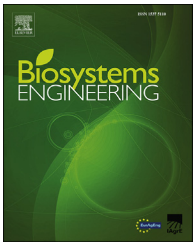

Research Paper

Performance analysis of a novel cyclone-type pneumatic rice polisher

Ch. Someswararao, Swati Mahato, Lobzang Namgial, Muhammed Sirajul Huda, Susanta Kumar Das[*]

Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur 721302, India

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Energy intensive commercial abrasive-friction rice polishing systems with heavy moving parts induces considerable breakage of rice. Jet polishing, used for metals with high speed air-abrasive particles, could be adopted to develop a simple pneumatic rice polishing system without any moving parts. Its construction is similar to a gas-cyclone system. The effect of four abrasive surfaces, viz., coarse (CR, 483 μm), medium (MD, 254 μm), fine (FN,122 μm) and very fine (VF, 89 μm) on degree of polishing (D_P) and broken yield (B_r) was studied. Particle-trajectory, particle-abrasive surface interaction, grain rotation pattern and progress of bran removal were also studied. D_P and B_r increased linearly with number of passes for all the abrasive surfaces. Higher D_P (8.49 ± 0.2 and 8.49 ± 0.3%) with CR and MD was attributed to removal of bran layer along with endosperm fractions while FN and VF removed proportionally more bran layer (D_P, 6.27 ± 0.3 and 8.31 ± 0.4%) with negligible endosperm fraction. B_r was least (24.13 ± 0.5%) with VF and highest (34.0 ± 2.2%) with CR.

1. Introduction

Rice polishing, also known as whitening of rice, is an important step in the whole rice milling process. It converts de-husked rice (called brown rice) into edible kernels by removing the outer bran layer of the kernel. It is composed of germ, pericarp, tegument and aleurone fractions. The aleurone layer is thicker at the dorsal than at the ventral side, and thicker in short-grain than in long-grain rice (Juliano, 1993). In most of the commercial processes, this polishing action may extend deep into the endosperm for glossy and white appearance of the final rice; consequently it gives higher selling price.

Polishing is the most energy intensive operation (Mohapatra & Bal, 2010). Modern rice mills use a combination of abrasive and friction polishers. All these polishers induce high shearing action on the rice kernels under high pressure (5–10 kPa), involving intense inter-granular attrition and high rate of friction with the abrasive surface (Satake, 1994). Along with these factors, generation of high temperature at the polishing zone and consequently development of thermal stress in the kernel induces significant breakage in commercial rice polishers. Ultimately it lowers the head rice yield. Mohaptra and Bal (2004) observed that a 1 °C rise in temperature of the bulk grain above 35 °C resulted in 1.5–2% extra broken grains in final milling output. Additionally, these polishers have heavy moving parts that suffer excessive wear and tear; and thus incur a high maintenance cost. In an ideal condition, 33% of the total energy is consumed for milling, 10% of it is converted into heat that increases grain temperature and the rest is utilised in running the machine (Mohaptra & Bal, 2004).

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[*] *Corresponding author.*
E-mail address: susantaiitkgp@gmail.com (S.K. Das).

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A new concept for carrying out the whitening action on rice has been attempted using the principle of jet polishing which is used commercially for polishing and scouring of metal surfaces. In this metal polishing, a two-phase system of abrasive particles and air under high pressure is allowed to strike on the metal surface at very high velocity. A similar principle but with modified approach has been reported for polishing of brown rice by Prakash, Someswararao, and Das (2014) in their development of a pneumatic polisher. The polishing or scouring action on the surface of the rice grains was carried out with a two-phase high speed flow of air and brown rice (as feed) inside a pipe. An abrasive surface was laid on the pipe wall. A 180°-scroll was installed at the entry end to induce a swirling action in the two-phase flow. This simple pneumatic polishing system, without any moving parts and with negligible thermal and compressive stresses, was found successful in carrying out control level of polishing of rice grains with yield of broken grains as low as 8.52% compared to 20% in laboratory abrasive polisher. This system has been carefully examined further by the present authors and some drawbacks have been identified. These were restriction of flow with the formation of dunes; large pressure drop with excessive friction in the pipe, scouring action restricted to the horizontal part of the pipe as well as some degree of non-uniform polishing or biased scouring action with the natural position or orientation of the grains in the flow channel. In order to overcome some of these drawbacks and to increase the effective polishing of grains with a compact system, a further modification of this system has been undertaken followed by detailed study on its polishing performance.

The developed system (Someswararao, Das, Prakash, & Sahu, 2015) consists of a gas cyclone type construction made with metal sheet. It comprises a short cylindrical part followed by a long conical part. The inner surface of the equipment has been provided with a hard abrasive layer for adequate scouring of bran layer from the kernels. The feed (pneumatic conveying of rice) enters the cyclone tangentially, and the two phase flow occurs in a helical path in which heavy rice grains move all along the abrasive wall under the action of centrifugal force (effective grain-abrasive surface interaction) while the individual rice grain also swirls or rotates randomly on its own axes This composite movement of rice and air over the abrasive surface performs the scouring action (polishing) on the grains. Finally, the polished grain gets discharged at the bottom and the air leaves from the top outlet of the cyclone.

Beside the mode of action as described above, several interrelated or interacting factors influence the performance of this developed pneumatic polishing system. These are identified as machine factors (constructional features), material factors (condition of the rice grain) and operational factors (flow and feed rate). The present study investigates the effects of different abrasive surfaces on the degree of polishing of the rice and yield of broken rice. For better understanding of the mechanism and effective zone of polishing, as well as performance analysis of the system, factors like trajectory of the grain particles, effective rice-abrasive surface interaction, movement patterns of the rice kernel inside the system, and progress of scouring action on the grain during its travel time have also been investigated using different simulation techniques and high-speed photography.

2. Materials and methods

2.1. *Pneumatic rice polishing system*

The improved pneumatic rice polishing system has no moving parts. Basically it comprises an upper cylindrical part and a conical bottom part; similar to that of a cyclone separator as shown in Fig. 1a. In this study, a system having a0.15 m diameter cylinder and0.8 m high polisher was selected. The cylindrical part consisted of an inlet port (feed inlet) provided with 180°-scroll. This facilitated two-phase tangential flow of air and brown rice at the entry. The inside surface of the polisher was layered with four grades of hard abrasive particles (Concord, India). These were categorised as very fine (VF), fine (FN), medium (MD) and coarse (CR) depending upon their grit sizes as commonly expressed in industry; 150, 100, 60 and 36, respectively. Corresponding average particle dimensions were 89, 122, 254 and 483 μm (*vide* Fig. 1b). Air velocity of 30 $\mathrm{m\ s^{-1}}$ was used. This flow rate was adequate for generating a high centrifugal force on the rice grains (terminal velocity of rice is around 6.0 $\mathrm{m\ s^{-1}}$) for its movement along the abrasive surface. Additionally, rotational and random motions of the rice grains about their own axes were expected inside the polisher. A bran collection unit was attached at the outlet end of the polisher. It consisted of two concentric cylinders – the inner cylinder had perforations. The final stream of bran and polished rice mixture at the outlet passes through the bran separator where bran particles escapes through the perforations and is deposited in the outer chamber of the cylinder. Polished rice is collected at the bottom of the system. The air escaped at the top and carried very fine bran particles with it.

2.2. *Raw material*

A particular variety of rice (Annapurna; l/b ratio 2.22 ± 0.2) was collected from the local market. This variety was chosen because of its naturally occurring pigment (purple to light brown colour) in the bran layer (Fig. 2). This facilitated easy visualisation and better comparison of the progress of bran removal from the kernel surface under different operating conditions. The un-polished rice (brown rice) was obtained by de-husking the paddy using laboratory rubber roll Sheller (Satake Corporation, Model THU35A, Japan). Moisture content of brown rice after de-husking was kept around 11–12% (wb) as recommended for commercial polishing of raw rice (Afzalinia, Shaker, & Zare, 2004).

2.3. *Performance evaluation of pneumatic polishing system*

Experiments were carried out with four abrasive surfaces as stated above. Before feeding into the system, the ‘brown rice’ was graded using a laboratory rice grader to remove all broken grains initially present; i.e., only whole kernels were taken for the polishing. A general factorial design was adopted. Each set of experiments with any particular abrasive surface was carried out with 200 g graded brown rice. The inlet air velocity and feed rate were maintained at 30 $\mathrm{m\ s^{-1}}$ and 1.25 $\mathrm{kg\ min^{-1}}$, respectively. Since the grains could not be polished in a single