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Performance Analysis of an Impeller Husker considering the Physical and Mechanical Properties of Paddy Rice

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Some physical and mechanical properties of three varieties of rice namely; Akitakomachi (short grain), Delta and L201 (long grain) were determined and used in the performance analysis of an impeller husker. Grain motion on the blade was observed at the rated impeller speed of 2362 min^{-1} using a high-speed camera. The grain exit velocity resulted in an impact force above the yield force of the husk but below the yield force of the grain. However, the maximum friction force experienced on the blade was far below the yield shear force of the husk for all three varieties of rice. Husking tests were performed at different impeller speeds using a hard urethane liner, a soft polystyrene liner and without a liner. Type of liner significantly affected the husking performance. Short-grain rice had high husking energy capacity and cracked grain ratio, but a low broken grain ratio compared with long-grain rice. Performance curves for the three varieties of rice were well expressed by the Weibull's distribution function.

1. Introduction

Grain properties significantly affect their processing characteristics (Mohsenin, 1970; Sitkei, 1986), thus a clear understanding of their processing characteristics is important in minimizing losses and optimizing production to achieve higher efficiency. Since grain property variation is wide, especially when considering variety difference, rice cannot be considered to have uniform properties. Differences in grain properties can result in a significant variation in the processing characteristics of the grain. Nishiyama *et al.* (1992) simulated grain motion in the impeller husker and showed that husking occurs by friction and impact force. Yamashita (1993) in his case suggested that 20% to 50% of paddy is husked by the friction force on the impeller blade. However, there has been no link made between the husking performance of the husker and the properties of the grain. Due to the friction and impact force involved, emphasis is put on the removal of the husk with minimum energy and grain damage (Nishiyama, 1995). This requires optimization. Thus the objectives of this paper were:

(1) to determine some physical and mechanical properties of three different varieties of rice that relate to impeller husker performance;
(2) to evaluate the dynamic flow of paddy rice in an impeller husker and the effect of the impeller speed and liner type on the husking performance; and
(3) to develop empirical relations between performance and operation parameters based on Weibull's distribution function and thus optimize the husking performance.

2. Theoretical consideration

2.1. *Impact force analysis*

The basic equation for the impact of a body of mass m in kg, with initial velocity v_1 in m s^{-1}, before impact and final velocity v_2 in m s^{-1}, after impact, expressed as a change in momentum is given by

$$mv_1 - mv_2 = \frac{P_{\max}\Delta t}{2} \tag{1}$$

Notation

a, a_0, a_1, a_2, a_3	equation coefficient	t	time, s
B	broken grain ratio, %	Δt	duration of impact, s
b, b_3	equation coefficient	v_1	initial velocity, m s^{-1}
C	cracked grain ratio, %	v_2	final velocity, m s^{-1}
c, c_0, c_1, c_2, c_3	equation exponent	w	specific energy, kJ kg^{-1}
d	thickness of rough rice, m	X	operation parameter
E	Young's modulus, kN m^{-2}	X_0	minimum value of operational parameter
F_B	bio-yield force, N	Y	performance parameter
F_Y	yield force, N	Y_e	equilibrium performance value
F_s	shear force, N	Y_0	initial performance value
h	width of rough rice, m	z	deformation during compression of grain, mm
H	husked ratio, %	z_0	maximum deformation of grain, mm
k	gradient of force–deformation curve	α_r	radial acceleration, m s^{-2}
l	length of rough rice, m	α_T	transverse acceleration, m s^{-2}
m	mass, kg	β	equation coefficient
N	impeller speed, min^{-1}	γ	Poisson's ratio
N_{OPT}	optimal impeller speed, min^{-1}	η	energy efficiency, kg kJ^{-1}
N_0, N_1, N_2, N_3	minimum impeller speeds, mim^{-1}	θ	total angle of rotation of the grain, rad
P	normal force, N	μ	coefficient of friction
P_{max}	maximum impact force, N	ϕ	angular blade curvature, rad
R^2	correlation coefficient	ϕ_r	first derivative of ϕ with respect to r
r	radial displacement of grain, m	ϕ_{rr}	second derivative of ϕ with respect to r
r_g	radius of curvature of paddy rice, mm	ϕ_t	first derivative of ϕ with respect to t
r_0	initial radial position of grain, m	ϕ_{tt}	second derivative of ϕ with respect to t
r_1	maximum radial displacement, m	χ	constant
S	sphericity	Ψ	angle between the tangent to the blade and the radial direction, rad
		ω	angular velocity, rad s^{-1}

where P_{max} is the maximum impact force in kN, arising during impact at an arbitrary time Δt in *s*. The maximum impact force may be determined from the kinetic energy equation as shown below:

$$\frac{mv_1^2}{2} = \int_0^{z0} P\,\mathrm{d}z \tag{2}$$

where: P is the normal force in kN; z is the grain deformation in m; and z_0 is the maximum deformation in m, during impact. Based on Boussinesq theory (Sitkei, 1986), the grain deformation z during compression under a plane plate is expressed as

$$z = \left[0{\cdot}5625\left(\frac{1-\gamma^2}{Er_g^{0.5}}\right)^2\right]^{0{\cdot}33} P^{0{\cdot}67} = kP^{0{\cdot}67} \tag{3}$$

where γ, E and r_g are Poisson's ratio, Young's modulus in kN m^{-1}, and radius of curvature in m, respectively. The coefficient k is the gradient of the force–deformation curve of the grain. If the constant χ is given by

$$\chi = \frac{(1-\gamma^2)}{Er_g^{0{\cdot}5}} \tag{4}$$

then

$$\chi = 1{\cdot}33333k^{1{\cdot}5} \tag{5}$$

Substituting χ in the equation below gives the maximum deformation z_0 during impact for a spherical body:

$$z_0 = (0{\cdot}9375mv_1^2\chi)^{0{\cdot}4} \tag{6}$$

The duration of impact Δt is approximated from the following equation:

$$\Delta t = 2{\cdot}94\left(\frac{z_0}{v_1}\right) \tag{7}$$

The radius of curvature of grain is approximated from its length l in m, and thickness d in m, by the following