

# Performance Analysis of Impeller and Rubber Roll Husker Using Different Varieties of Rice

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## Abstract

*Performance analysis of experimental impeller and rubber roll huskers was carried out using three different varieties of rice namely; Akitakomachi (short grain), Delta (long grain) and L201 (long grain). Impeller husker speed was varied from 1400 to 3300 rev/min and rubber roll husker clearance was varied from 0.4 to 2.4 mm. In rubber roll husker, rough rice was husked randomly and as single grain vertically and horizontally. For both huskers, variation of husked ratio with specific husking energy was well expressed by the Weibull's distribution function. Husking energy efficiency, system cracked ratio and system broken ratio curves were well expressed by the empirical equations. The three performance parameters were used to optimize the husking performance of the two huskers for the three varieties of rice. Rubber roll husker had high husking energy efficiency compared to impeller husker for randomly husked short grain rice and for all the three varieties of rice husked as single grain. Optimal husked ratio in terms of husking energy efficiency was also found to be optimal in terms of system cracked ratio and system broken ratio for all the three varieties of rice.*

**Keywords.** *Impeller husker, Rubber roll husker, Husking energy efficiency, System cracked ratio, System broken ratio*

## 1. Introduction

### 1.1 Husking theory

Husking involves the removal of the husk from rough rice by shear or impact force, and modern husking methods involve the use of impeller and rubber roll huskers (Juliano, 1985; Yamashita, 1993). During husking, the grain is subjected to various forces, which apart from husking also result in grain damage and depends on the direction of grain feed (Yoshizaki and Miyahara, 1984). Thus a clear understanding of the grain's husking characteristics is important when considering the husking performance of huskers. In this paper, the operation parameter  $X$  like impeller speed or roll clearance is defined as input and the performance parameter  $Y$  like husked ratio is defined as the output. Performance parameter can therefore be expressed as a function of the operation parameter  $F(X)$  as shown below (Shitanda, *et al.*, 2000):

$$F(X) = (Y - Y_e) / (Y_0 - Y_e) \quad (1)$$

where  $Y_0$  and  $Y_e$  are the initial and equilibrium or maximum performance values respectively.

For performance parameter like husked ratio expressed as a percentage,  $Y_0 = 0\%$  and  $Y_e = 100\%$ . Thus equation (2) gives the expression for the performance parameter  $Y$  based on the Weibull's distribution function as proposed by Nishiyama *et al.* (1992). It consists of a fixed initial or allowable maximum operation value  $X_0$  and a variable operation parameter  $X$ :

$$Y = 100 - 100 \exp\left(- (a(X_0 - X))^b\right) \quad (2)$$

where  $a$  is equation coefficient and  $b$  is equation exponent dependent on grain variety. If the husked ratio  $H\%$  is taken as a performance parameter when specific husking energy  $E$  in kJ/kg is the corresponding operation parameter, then husking energy efficiency  $\eta$  in kg/kJ is given by the equation below (Nishiyama, 1995; Shitanda, *et al.*, 1999a):

$$\eta = H / 100 E \quad (3)$$

At maximum husking energy efficiency, the husked ratio  $H_{OPT}$  is referred to as optimal husked ratio. Sugawara (1995) showed that specific husking energy for the impeller husker depends on the impeller speed  $N$  in rev/min and is given by:

$$E = kN^2 \quad (4)$$

where  $k$  is equation coefficient. For rubber roll husker, contact distance  $l_d$  between the roll and the grain considering the radius of curvature  $r_g$  of the grain given by (Shitanda, *et al.*, 1999b):

$$l_d = 2\sqrt{2r_r\alpha - \alpha^2} \quad (5)$$

where,  $r_r$  is the roll radius and  $\alpha$  is given by the following equation:

$$\alpha = (r_g \delta - 0.5 \delta^2) / (r_g + r_r - \delta) \quad (6)$$

where  $\delta$  is maximum roll deflection when the grain goes through the husker. It depends on the

grain thickness  $w$  and roll clearance  $C$  as in the following equation:

$$\delta = (w - C) / 2 \quad (7)$$

Nishiyama (1995) showed that specific husking energy for rubber roll husker depends on the coefficient of friction  $\mu$ , specific normal force  $p$  in kN/kg, peripheral velocity difference (PVD) ratio  $\phi_n$ , and contact distance  $l_d$  in m. It is expressed by the following equation:

$$E = 2 \mu p \phi_n l_d \quad (8)$$

The product of coefficient of friction and specific normal force gives the specific husking shear force. If the main roll has a diameter  $D$  in m and rotates at a speed of  $N$  in rev/min, and the auxiliary roll has a diameter  $d$  in m and rotates at a speed of  $n$  in rev/min, then PVD ratio is given by:

$$\phi_n = (DN - dn) / dn \quad (9)$$

The peripheral velocity difference (PVD) ratio is a measure of the relative velocity between the main roll and the auxiliary roll.

Due to the importance of energy and grain quality during processing, this study aimed at comparing and optimizing the husking performance of impeller and rubber roll husker based on husking energy efficiency, system cracked ratio and system broken ratio.

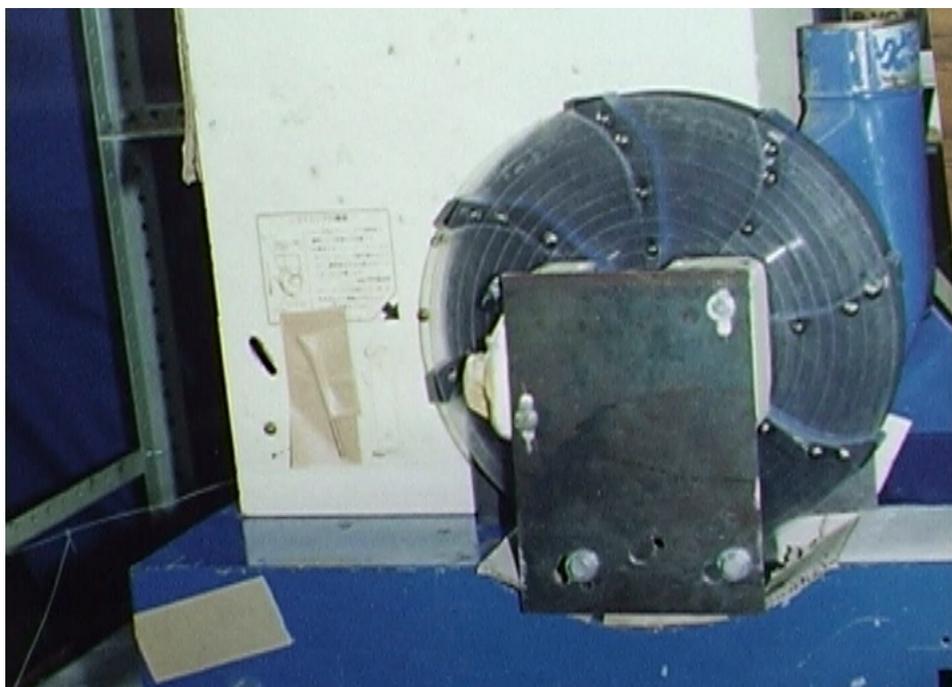
## 2. Materials and Methods

Three varieties of rice, namely Akitakomachi, Delta and L201 were husked using an experimental impeller husker (OHTAKE FC4S) with 8 blades and rubber roll husker (SATAKE THU) with two rolls of 0.1 m diameter, rated peripheral velocity difference ratio of 0.83 and of Shore hardness 82 (fig. 1). Impeller husker had a capacity of 200 kg/h and that for rubber roll husker was 100 kg/h. Based on their size, Akitakomachi was classified as short grain whereas Delta and L201 were classified as long grain. Grain parameters determined were; moisture content, grain length  $l$ , width  $h$  and thickness  $w$ , radius of curvature  $r_g$ , sphericity  $S$  and mass  $m$ .

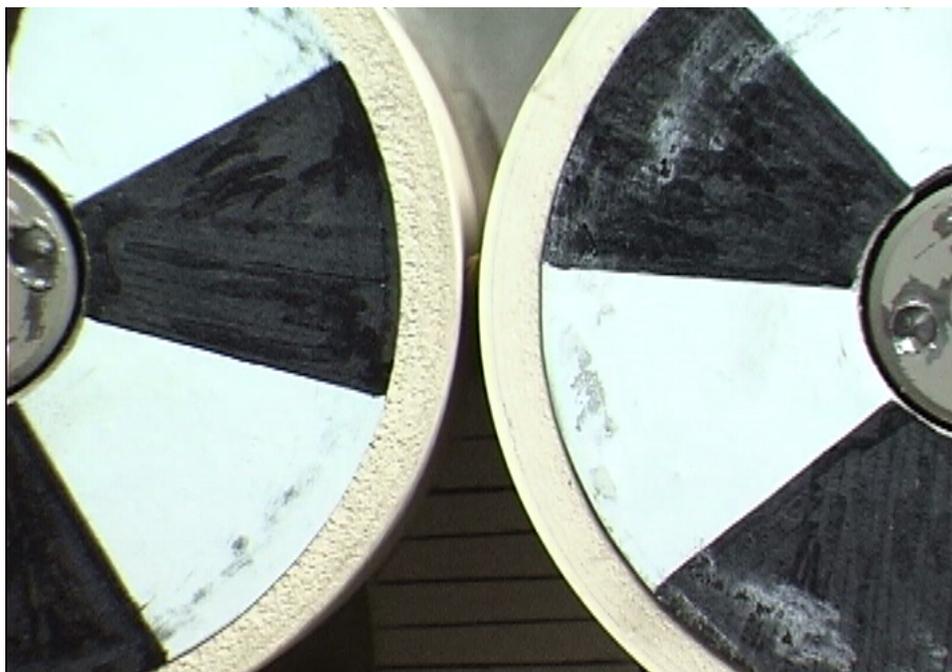
For impeller husking, impeller speed was varied from 1400 to 3300 rev/min using an inverter (SANKEN ELECTRIC CO. SANCO.M MT-2), and measured by a digital contact tachometer (ONO SOKKI HT3100). About 50g of rough rice at 15 % w.b moisture content was husked randomly in the impeller husker. During husking by rubber roll husker, the roll clearance was varied from 0.4 to 2.4 mm at an interval of 0.2 mm by use of filler gauges. At the rated roll speed ( $N = 1895$  rev/min,  $n = 1035$  rev/min), about 50 g of rough rice was husked randomly at the rated peripheral velocity difference ratio. Rough rice was also husked as single grain (one grain at a time) vertically and horizontally at the rated PVD ratio.

For both the two huskers, data collected included weight of unhusked rough rice, husked brown rice, cracked brown rice, and broken brown rice. Husked ratio, cracked ratio and broken ratio were computed as a fraction of the supplied rough rice. Cracks were observed by a grain scope (KETT TX-200) and a digital power meter (HIOKI 3184) was used to measure husking power for random grain feed. For single grain feed, specific husking energy was computed by equation (8) using shear force obtained from a stress-strain tester (SHIMPO FG 50V) used to rotate the main roll. Maximum shear force was taken as the husking force. Equation parameters

were obtained by least square method.



(a) Impeller husker showing the blades (OHTAKE FC4S)



(b) Rubber roll husker showing the rolls (SATAKE THU)

Figure 1 Experimental rough rice huskers

### 3. Results and Discussion

#### 3.1 Grain properties

Properties of the three varieties of rice husked using impeller and rubber roll husker are given in table 1. Akitakomachi was short but thicker with a length  $l$  of 7.3 mm, and thickness  $d$  of 2.3 mm whereas L201 was long but thinner. Although the Delta variety had a thickness of about 2.2 mm it could not be considered as medium grain due to its length. Akitakomachi had the highest sphericity of 0.52 followed by Delta and L201 had the lowest. It however had the lowest radius of curvature of about 6.4.

Table 1 Grain properties

| Rice Variety | $l$<br>(mm) | $h$<br>(mm) | $w$<br>(mm) | $r_g$<br>(mm) | $S^*$ | $m$<br>(g) |
|--------------|-------------|-------------|-------------|---------------|-------|------------|
| Akitakomachi | 7.3         | 3.3         | 2.3         | 6.3           | 0.52  | 0.0286     |
| Delta        | 10.0        | 3.2         | 2.2         | 11.9          | 0.41  | 0.0374     |
| L201         | 9.8         | 2.5         | 2.0         | 12.5          | 0.37  | 0.0275     |

$l$ : length,  $h$ : width,  $w$ : thickness,  $S$ : sphericity;  $m$ : mass

\*Sphericity =  $\sqrt[3]{lhw}/l$ , Mohsenin, 1970.

#### 3.2 Husked ratio

Husked ratio of the three varieties of rice husked by impeller and rubber roll husker increased with increase in specific husking energy as shown in figure 2 and 3. Experimental results were well fitted by the following equation with a high correlation coefficient  $R^2$  of over 0.9.

$$H = 100 - 100 \exp\left(- (a_1 E)^{b_1}\right) \quad (10)$$

Equation coefficient  $a_1$  and exponent  $b_1$  for random and single grain feed are given in table 2. For both impeller and rubber roll huskers, short grain rice Akitakomachi with high sphericity had higher husked ratio compared to long grain Delta and L291. However, the difference between the husked ratios for short and long grain rice was much wider for rubber roll husker than for impeller husker. This showed that the performance of rubber roll husker is very much dependent on the size and shape of rough rice unlike for impeller husker.

**Table 2 Equation parameters for different types of grain feed**

| Grain variety | Type of grain feed |            |          |       |            |       |
|---------------|--------------------|------------|----------|-------|------------|-------|
|               | Random             |            | Vertical |       | Horizontal |       |
|               | $a_1$              | $b_1$      | $a_1$    | $b_1$ | $a_1$      | $b_1$ |
| Akitakomachi  | 0.511(0.334)*      | 3.00(3.32) | 0.760    | 1.83  | 1.278      | 1.75  |
| Delta         | 0.253(0.271)       | 4.24(2.85) | 0.475    | 2.70  | 1.130      | 1.96  |
| L201          | 0.210(0.257)       | 6.00(2.79) | 0.250    | 3.85  | 0.834      | 3.47  |

\*Values in parenthesis are for impeller husker

Randomly husked short grain rice had higher husked ratio for rubber roll husker than for impeller husker (fig. 2).

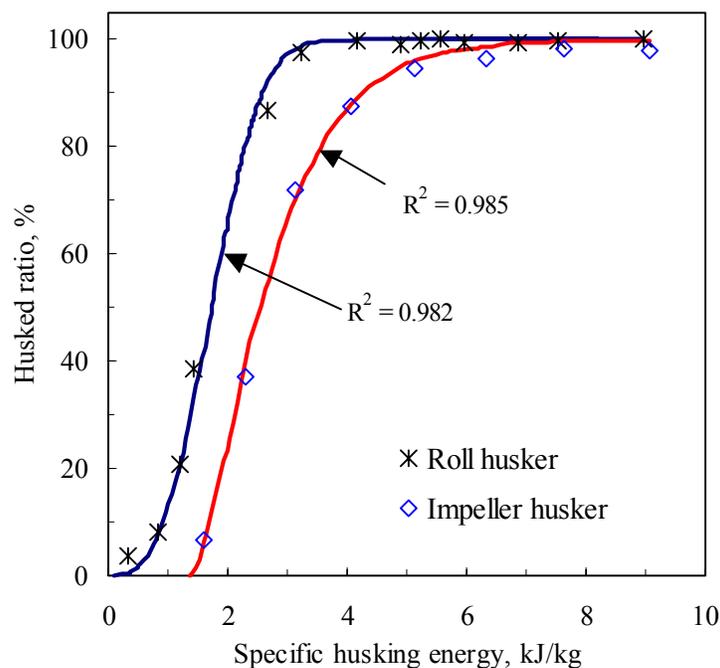
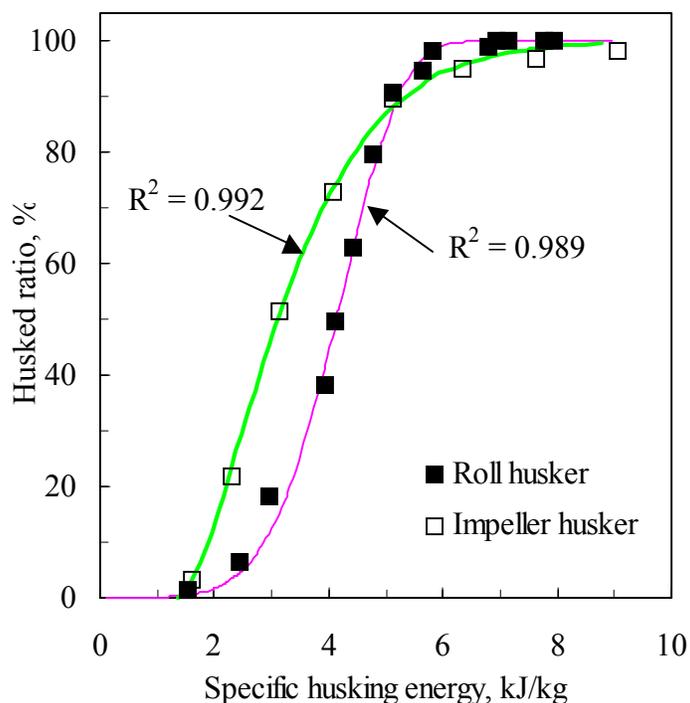


Figure 2 Husked ratio for Akitakomachi variety husked randomly

by impeller and rubber roll husker

The converse was however true for long grain rice below 90% husked ratio as shown in figure 3. Short and long grain rice husked as single grain in rubber roll husker, had high husked ratio compared to impeller husker (fig. 4). Thus single grain feed had a better husking performance compared to random grain feed. Husked ratio for horizontal grain feed was also higher than that for vertical grain feed. This may be attributed to the easy tendency of the grain to turn when fed horizontally and the difficulty of shearing off the husk along the grain length.



(a) Delta variety

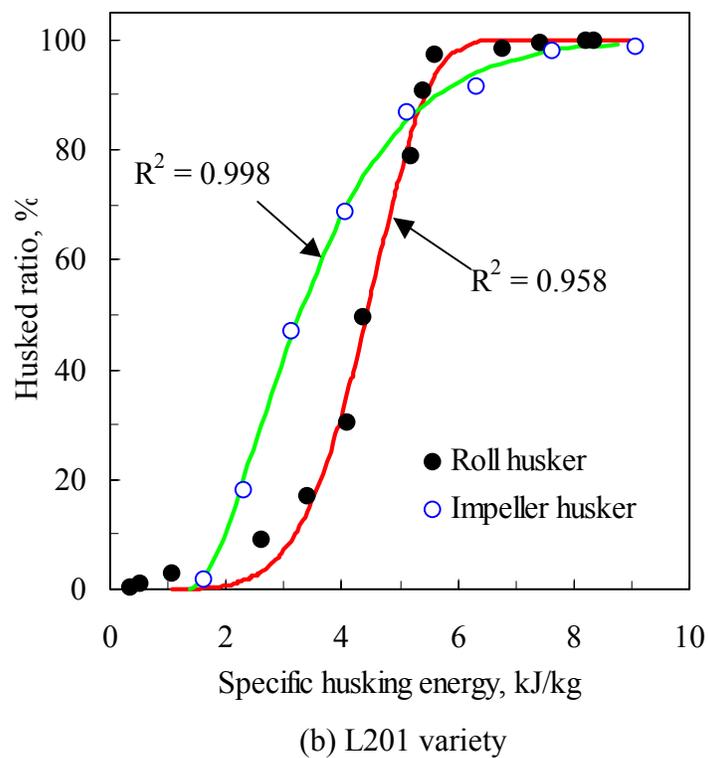
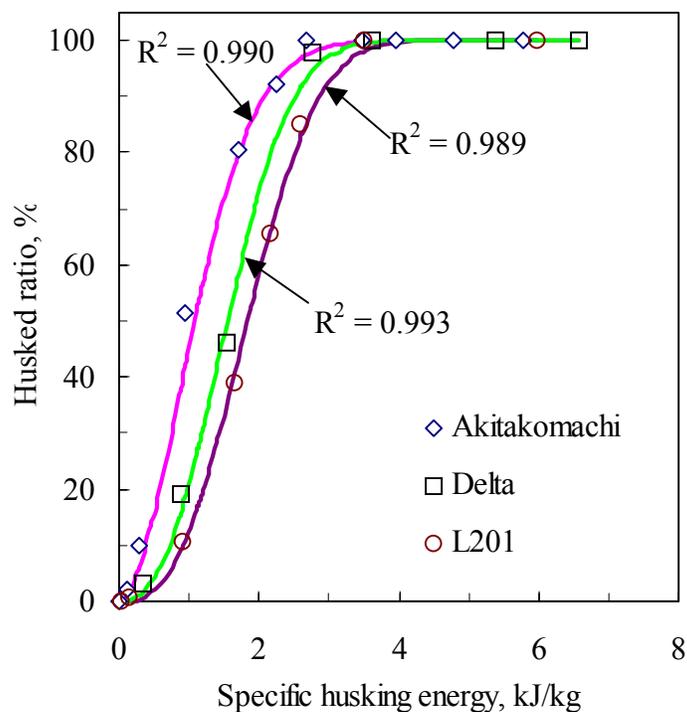
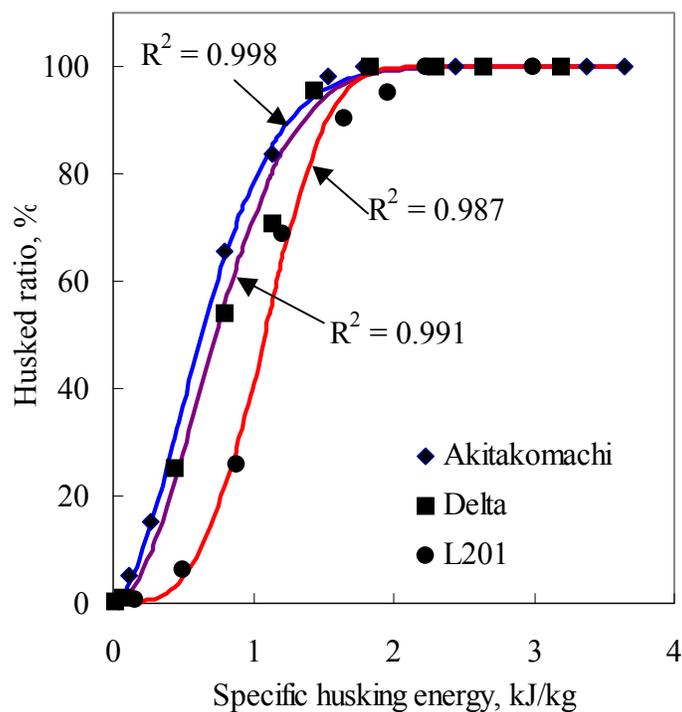


Figure 3 Specific husking energy for randomly husked long grain rice



(a) Vertical grain feed



(b) Horizontal grain feed

Figure 4 Variation of husked ratio with specific husking energy

for single grain feed

### 3.3 Husking energy efficiency

Husking energy efficiency curves for the two huskers were computed using equation (3). Short grain rice had higher husking energy efficiency compared to long grain rice for both impeller and rubber roll husker irrespective of the direction of grain feed. However, short grain rice husked randomly by rubber roll husker had higher husking energy efficiency compared to impeller husker (fig. 5).

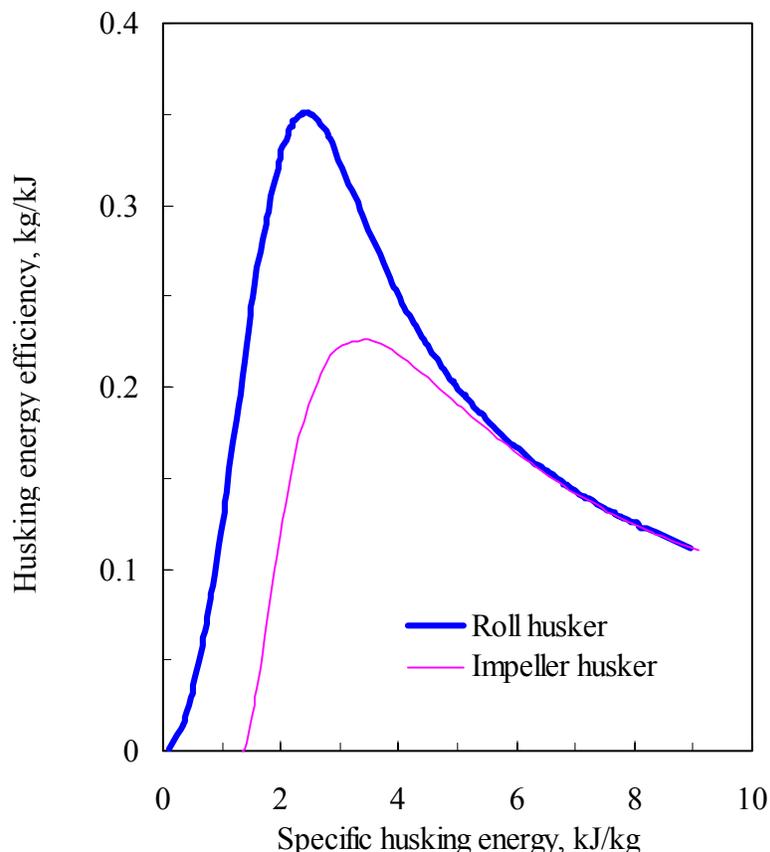
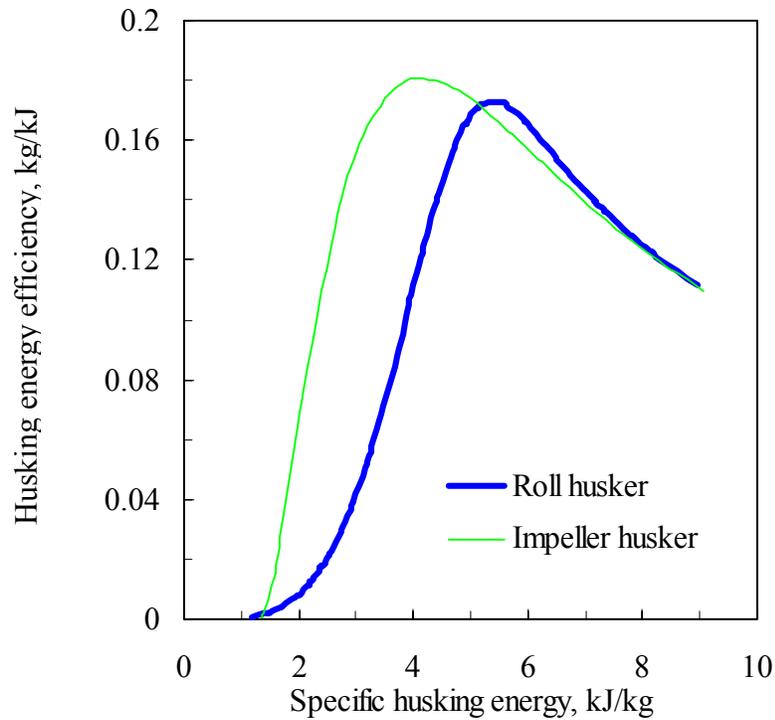


Figure 5 Husking energy efficiency curves for Akitakomachi variety husked randomly by impeller and rubber roll husker

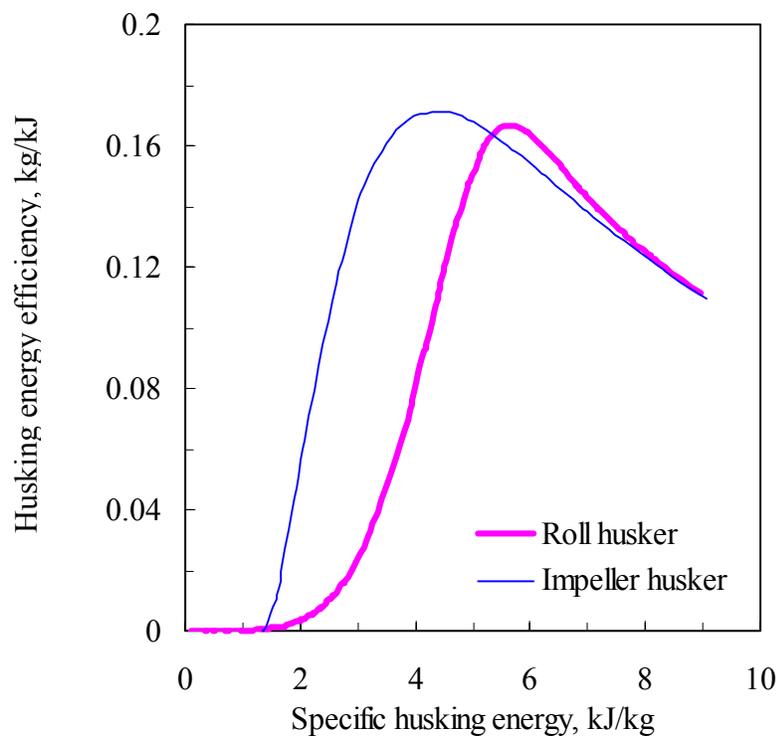
The converse was true for randomly husked long grain rice as shown in figure 6 (a) and (b), but the maximum husking energy efficiency for the two huskers were almost the same.

Figure 7 shows the husking energy efficiency for single grain feed of the three varieties of rice. Vertical grain feed had lower husking energy efficiency compared to horizontal grain feed as shown in figure 7 (a) and (b) for the three varieties of rice. Husking energy efficiency for vertical and horizontal grain feed was also higher than that for random grain feed in rubber roll husker and impeller husker. Thus based on husking energy efficiency for single grain feed,

rubber roll husker has better husking performance compared to impeller husker irrespective of the rice variety.

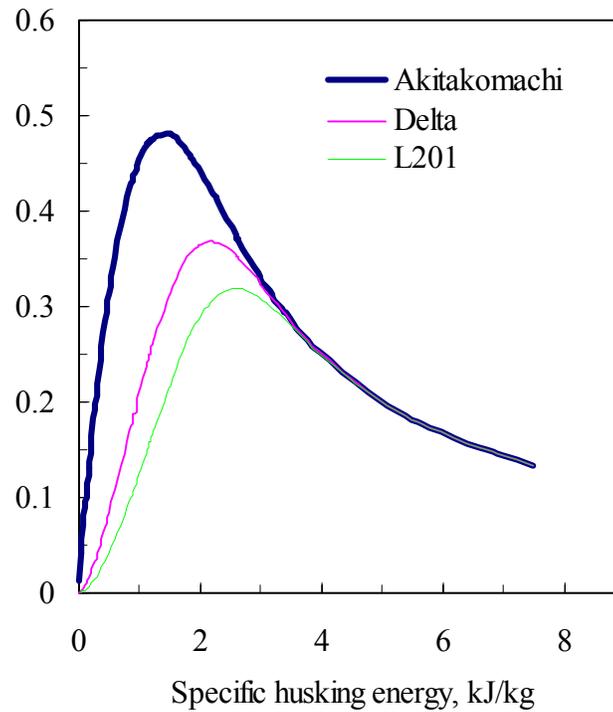


(a) Delta variety

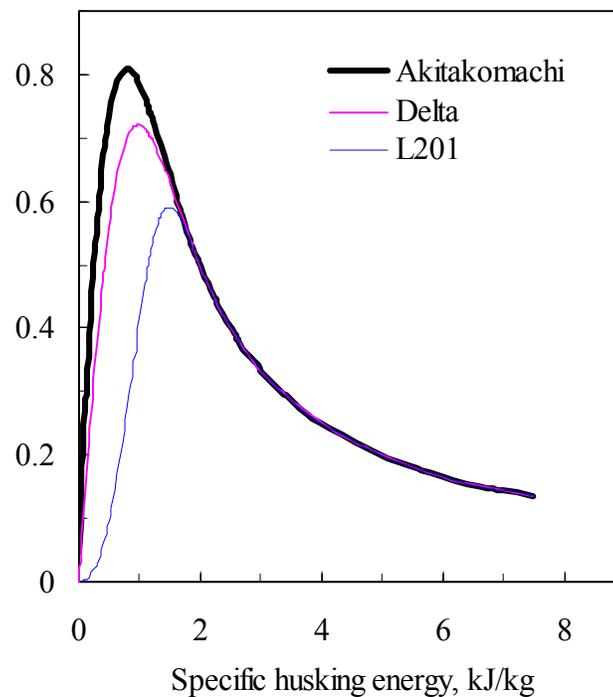


(b) L201 variety

Figure 6 Husking energy efficiency curves for randomly husked long grain rice varieties



(a) Vertical grain feed



(b) Horizontal grain feed

Figure 7 Husking energy efficiency curves for single grain feed in rubber roll husker

At the optimal performance point when husking energy efficiency is maximum, impeller husker had optimal husked ratio of about 78%, 74% and 73% for Akitakomachi, Delta and L201 respectively. Their corresponding optimal impeller speeds were 1655 rev/min, 1836 rev/min, and 1882 rev/min respectively. For random grain feed in rubber roll husker, optimal husked ratios were 86%, 90% and 92% for Akitakomachi, Delta and L201 respectively. Their corresponding optimal roll clearances were 1.8 mm, 1.5mm, and 1.3mm respectively. Results showed that rubber roll husker has better husking performance at the optimal performance point.

### 3.4 System cracked ratio

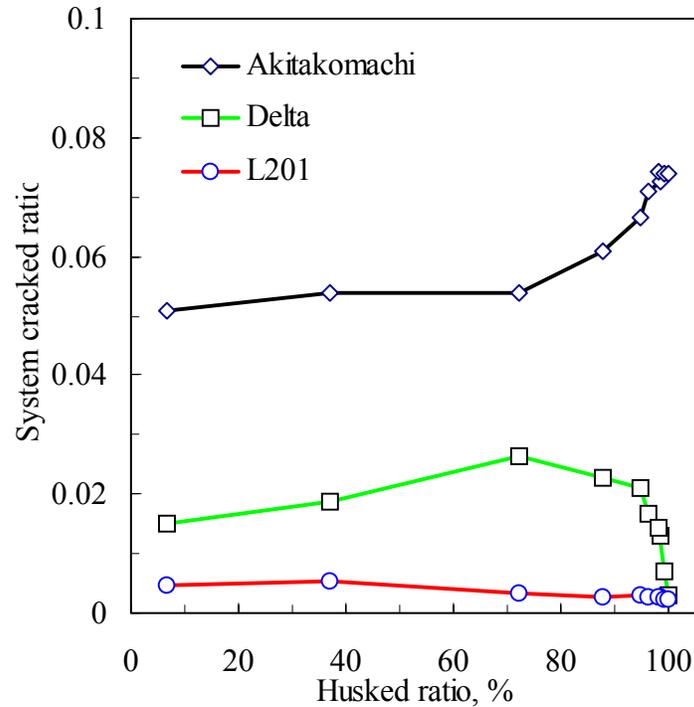
System cracked ratio  $S_c$  is an expression proposed by the authors for optimization of the husking performance. It relates the cracked grain and the husked grain as shown below:

$$S_c = C/H \quad (11)$$

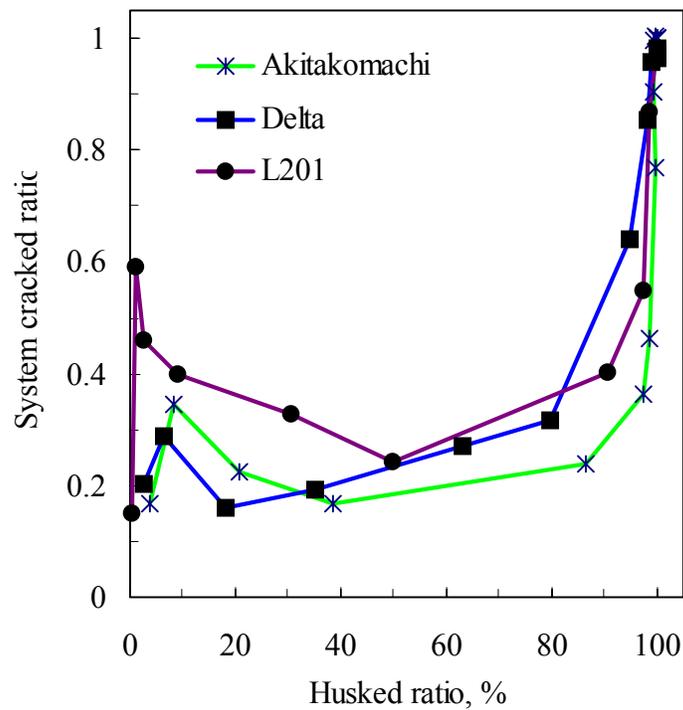
where  $C\%$  is cracked ratio and  $H\%$  is husked ratio. To minimize crack damage, system cracked ratio should be as low as possible without compromising the husking performance. Thus at the optimal performance point, high husked ratio with minimal cracked grain is preferable. From the experimental results, system cracked ratio for short grain rice husked by impeller husker was higher for short grain rice compared to long grain rice. Akitakomachi had the highest system cracked ratio followed by Delta and L201 as shown in figure 8(a). System cracked ratio for the three varieties of rice was relatively constant with increase in husked ratio up to a husked ratio of about 80%. At higher husked ratio, short grain rice showed a sharp increase whereas long grain rice showed a sharp decrease in system cracked ratio. The decrease in system cracked ratio for long grain rice may be attributed to increased grain breakage. The 80% husked ratio where a sharp change in system cracked ratio occurred was very close to the optimal husked ratio of the three varieties of rice. Thus impeller husker performance can also be said to be optimal where there is a sharp change in system cracked ratio.

Grain cracks in rubber roll husker were mainly at the surface and minor (Bautista, 1998) compared to those in impeller husker. System cracked ratio for random and single grain feed in rubber roll husker was also relatively constant with increase in husked ratio for the three varieties of rice but showed a sharp increase above 90% husked ratio as shown in figure 8 (b). However, there was no specific trend for short and long grain rice. The sharp increase in system cracked ratio also occurred close to the optimal husked ratio of the three varieties of rice. This also showed that a sharp increase in system cracked ratio in rubber roll husker occurred close to the optimal performance point.

Comparison of the two huskers showed that rubber roll husker had higher system cracked ratio for all the three varieties of rice compared to impeller husker. The high system cracked ratio for the three varieties of rice can be attributed to the shearing force resulting from the two rubber rolls, which tends to stretch the grain in between the rolls.



(a) Impeller husker



(b) Rubber roll husker

Figure 8 Variation of system cracked ratio with husked ratio for randomly husked rough rice

### 3.5 System broken ratio

System broken ratio  $S_B$  like system cracked ratio is an expression proposed by the authors for optimization of the husking performance. It is a measure of the broken grain per every husked grain and is given by:

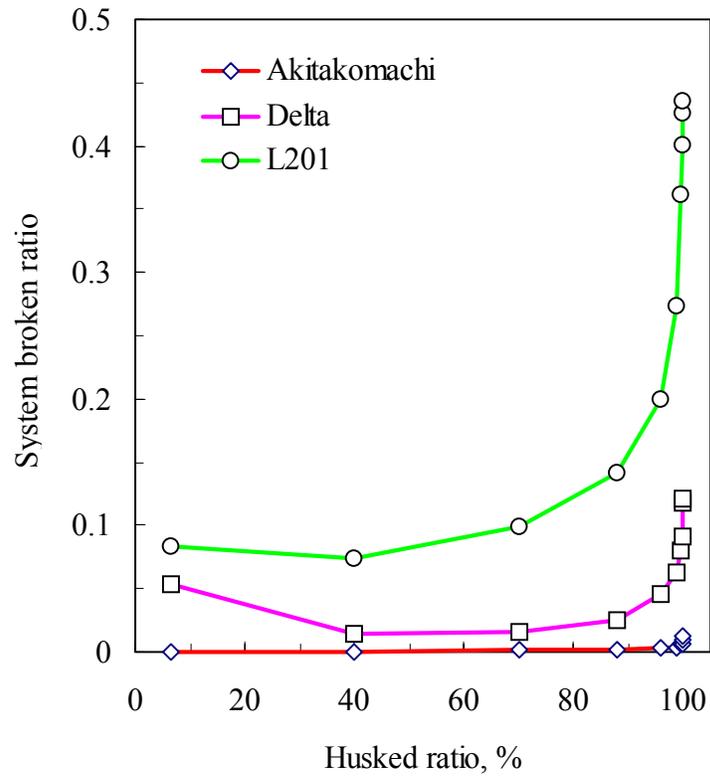
$$S_B = B / H \quad (12)$$

where  $B\%$  is broken ratio and  $H\%$  is husked ratio. System broken ratio should be kept low so as to minimize grain breakage during husking.

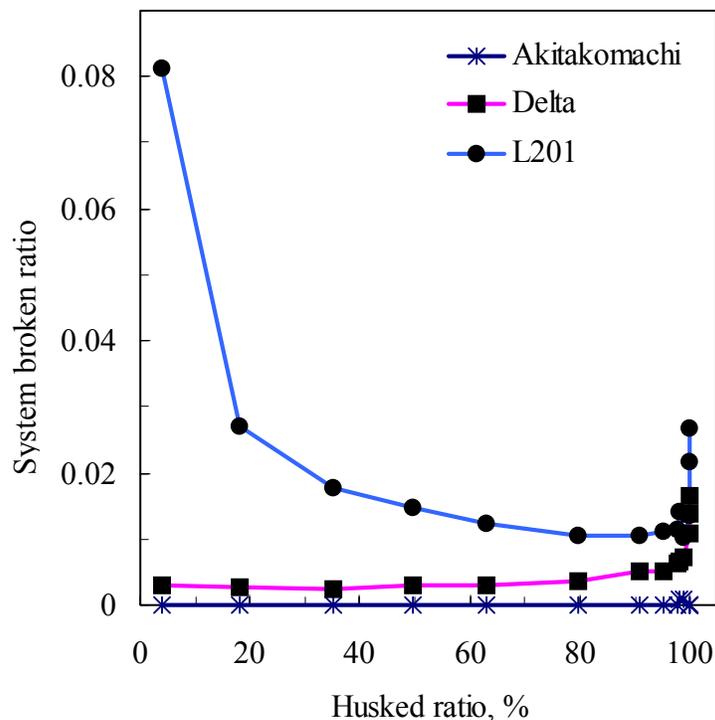
System broken ratio for impeller husker shown in figure 9 (a) was relatively constant with increase in husked ratio for the three varieties of rice. It then showed a sharp increase above 80% husked ratio. Long grain rice L201 had the highest system broken ratio followed by Delta and Short grain rice, Akitakomachi had the lowest. Results showed the high susceptibility of long grain rice to breakage. This can be attributed to their brittle characteristics and high impact force on the liner and by the blade. The sharp increase in system broken ratio also occurred close to the optimal husked ratio of the three varieties of rice.

System broken ratio trend for random grain feed in rubber roll husker was however quite different for L201 since it decreased sharply showing tendency to reach a constant and then increased again above 90% husked ratio. Long grain rice, L201 had also the highest system broken ratio followed by Delta and Akitakomachi as shown in figure 9 (b). Long grain rice had generally higher system broken ratio compared to short grain rice, which exhibited tough characteristics. System broken ratio trend for Delta and Akitakomachi was the same as for impeller husker since it remained relatively constant with increase in husked ratio up to about 90% husked ratio. A sharp increase then occurred as the husked ratio increased further. The sharp increase in system broken ratio for rubber roll husker also occurred close to the optimal husked ratio of the three varieties of rice. This showed that it was a vital indicator in the performance of the husker.

Unlike for system cracked ratio, impeller husker had high system broken ratio compared to rubber roll husker for all the three varieties of rice used. Since grain breakage is a major damage, low system broken ratio far outweighs low system cracked ratio. Thus rubber roll husker can be said to have advantage over impeller husker in terms of major grain damage especially for long grain rice.



(a) Impeller husker



(b) Rubber roll husker

Figure 9 Variation of system broken ratio with husked ratio for randomly husked rough rice

#### 4. Conclusion

Performance analysis of impeller and rubber roll huskers was carried out using three different varieties of rice. The husking performance curves were evaluated relating the performance and operation parameters using empirical equations. Optimization of the husking performance for the two types of huskers was achieved using husking energy efficiency, system cracked ratio and system broken ratio. From the results obtained, the following conclusions can be drawn.

- (1) Short grain rice has higher husking energy efficiency in impeller and rubber roll huskers compared to long grain rice.
- (2) Husking energy efficiency of rubber roll husker for single grain feed is higher than that for impeller husker irrespective of the rice variety. Thus single grain feed is a more suitable feed method compared to random grain feed.
- (3) Rubber roll husker and short grain rice have higher system cracked ratio compared to impeller husker and long grain rice respectively.
- (4) Optimal impeller and rubber roll husker performance in terms of husking energy efficiency is also optimal in terms of system cracked ratio and system and broken ratio.
- (5) Rubber roll husker is more suitable for husking short and long grain rice compared to impeller husker when considering husking energy efficiency and grain damage.

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