RESEARCH ARTICLE

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The effect of rice milling time and feed rate on head rice yield and color properties

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Abstract

This study has been carried out to evaluate the head rice yield, kernel broken and the chance of color depend on milling time and feed rate. In this study, threshed rice kernels by combine-harvester at different cylinder speeds, rice harvesting season in 2018, were used for experiment test. According to results, head rice yield decreased slightly as the cylinder speed increased, with yields varying between 71.40 % and 70.28 %. Processing time was found to have a highly significant effect ($p<0.01$) on the quantities of unbroken kernel, broken kernel, bran, yield and husk. The highest rate of broken kernel was obtained at a processing time of 25 seconds, and the lowest values were obtained at a processing time of 10 seconds. With a processing time of 10 seconds, the quantities of unbroken kernel, broken kernel, bran, yield and husk were 70.74, 3.260, 0.810, 74.37 and 24.82 %, respectively. When the processing time was 25 seconds, the quantity of broken kernel decreased from 70.74 percent to 62.86 percent, and yield decreased from 74.37 % to 67.58 %. The broken kernel ratio increased from 3.26 percent to 4.633 percent and bran ratio increased from 0.8642 percent to 1.822 percent. Husk ratio, on the other hand, increased from 24.82 % to 30.60 %. In other words, as the processing time increased, so did the bran ratio and husk ratio. The highest whiteness value of 70.92 was obtained at a processing time of 25 seconds; while the lowest whiteness value of 63.81 was obtained at a processing time of 10 seconds. There were declines in a and b values as processing time increased, although the differences were not statistically significant. The highest a and b values were obtained at a processing time of 10 seconds, with -0.690 and 15.01, respectively. In conclusion, when processing paddy to rice, processing time needs to be increased to obtain a whiter rice; to have fewer broken kernels and a higher head rice yield, on the other hand, the processing time needs to be short.

Keywords: Rice processing, Head rice yield, Rice breaking, Milling, Husking

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops, being an important source of food, energy and protein worldwide, and the main staple food of more than half the world's population (Roy et al., 2011; Kim and Lee, 2012). According to the FAO, global rice production was 759.6 million tons (503.9 million tons, milled basis) in 2018. Nearly 90 percent of the world's rice is grown and consumed in Asia by 60 percent of the world's population on about 11 percent of the world's cultivated land (Mejía, D.J. 2003; Buggenhout et al., 2013; FAO, 2018). The rice grain consists of the hull or husk (18–28%) and the caryopsis or brown rice (72–82%). Brown rice consists of an outer layer (pericarp, tegmen and aleurone layers) called bran (6–7%); the germen or embryo (2–3%); and the edible portion (endosperm 89–94%) (Mejía, D.J. 2003; Champagne et al., 2004; Delcour and Hoseney, 2010; Buggenhout et al., 2013; IRRI, 2019). Rice is also the most widely grown staple food, and is a basic source of livelihood for rural households around the globe, given its high economic value. The economic value of harvested rice is based the milled rice yield and the percentage of head rice (Kim and Lee, 2012). Consumers usually prefer milled rice. Before rice is consumed, the husk, bran and germ are removed from the rough rice kernel, and this "milling" operation is a crucial step in the post-production of rice (IRRI, 2019; Zhou et al., 2015). The processing of rice involves several operations. The rice is milled to separate the husk (dehusking) and the bran (polishing), leaving behind the edible portion (endosperm) for consumption. The removal of the rice bran layers in the milling process improves the appearance, cooking quality and palatability of rice, though a major loss of nutrients and high percentage of brokenness results from mechanical milling. For this reason, producing brown rice with minimum breakage in which the maximum possible nutrients are retained, and with preferable cooking attributes, has become the primary goal of the rice processing sector (Mithy et al., 2008; Razavi and Farahmandfar., 2008; Kim and Lee, 2012; Kumar and Kalita, 2017).

The processing of rice is carried out in factories or using a rice milling machine. Rice dehusking involves the removal of the husk and bran from the paddy rice to produce head white rice grains that are sufficiently milled, free from impurities and containing a minimum number of broken grains. The basic objective in a rice milling system is to remove the husk and the bran layers, and to produce an edible, white rice kernel that is sufficiently milled and free of impurities. Depending on the requirements of the customer, the rice should have a minimum number of broken kernels (IRRI, 2019), although during such processing, rice kernels are subjected to mechanical forces during several operations, such as harvesting, threshing, drying, dehulling and milling. When these forces exceed the strength of the rice grain, the individual rice grain breaks and the quantity of broken rice kernels increases depending on the intensity of the processing (Buggenhout et al., 2013). The tendency of rice kernels to break is primarily determined by the fissures, chalkiness, immaturity and dimensions of the rice kernel. Fissured kernels usually break during milling, leading to a reduction in head rice yield, which in turn results in a poor cooking quality and a lower market value (Zhang et al., 2005).

A main challenge faced by the rice sector is minimizing the quantity of broken rice (Buggenhout et al., 2013). If the rice milling machine and operations are not properly designed, rice kernel cracking and breakages increase, resulting in a low market price. The marketing of rice as an agricultural product depends on its physical qualities after processing. The percentage of whole grain is the most important parameter in the rice processing sector. The head rice yield in milling depends on the type of mill, milling cylinder speed, degree of milling, moisture content, milling procedure and the head rice separation method (Correˆa et al., 2007; Schluterman and Siebenmorgen, 2007; Kim and Lee, 2012).

Turkey is an important producer of rice, given the suitability of its climate, soil and environmental conditions. The southeastern part of Turkey, in particular, is an important rice-producing region, and is noted particularly for two rice varieties: Karacadağ Karakılçık and Karacadağ Beyaz, with 95 percent of the cultivation area and production being in the Karacadağ region. The main problems in rice production are the high rate of loss of broken rice kernels during the harvesting, threshing and post-harvesting processing stages (dehulling and milling) (Esgici et al., 2019).

In this study, we focus on the impact of dehulling (husking) and milling on kernel breakage during the processing of rice from the paddy. The study was carried out to identify means of reducing mechanical losses during the processing of rice. To this end, it examines the effect of processing time and the rice feed rate on head rice yield, the quantity of broken grain, bran and husk, and powdered rice, and the changes of color in rice threshed at different cylinder speeds by the combine harvester.

MATERIALS AND METHODS

Head Rice Yield, Broken Kernels, Bran Rate and Husking

The milling tests in the study were carried out in the Laboratory of the Department of Agricultural Machinery and Technologies Engineering, Diyarbakır, TURKEY. The commonly grown rice variety Karacadağ Karakılçık (dark) was used for the experiment (Figure 1). The moisture content of the rice kernel samples was measured according in accordance with ASABE standards (ASABE, 2008). Prior to testing, four samples of 25 g rice stems were weighed and dried in an oven at 103°C for 24 h, and were then reweighed to measure the average moisture content of the rice kernels, during which an average moisture content of 10.40 percent w.b was recorded. A moisture content of 14 percent MC is considered ideal for milling (IRRI, 2019). The rice milling machine used in the experiments is shown in Figure 1.

The milling machine comprises two rubber roll dehullers that rotate at different speeds in opposite directions for the husking – being the separation of the hull from the rough rice to obtain brown rice – milling and bran removal operations.

Figure 1. Rice Milling Machine

The experiments were carried on rice samples subjected to five different threshing cylinder speeds (650, 750, 850, 950, and 1050 rpm) in the combine harvester. The samples were taken from the threshed paddy for each cylinder speed, while four milling times (10, 15, 20 and 25 second) and four feed rates (20, 40, 60 and 80 gr) were used as independent parameters. The rice yield, broken kernel, bran rate, husking rate and change of color were measured for the different parameters.

The ratio (%) of broken kernels in milled rice was measured by way of a manual analysis using a naked eye identification method. A sub-sample of milled rice was divided visually into broken and whole grain groups. The quantity of broken kernels was calculated by dividing the weight of the broken kernels by the whole kernels, which was then expressed in the form of a percentage. The quantities of broken and unbroken kernels, bran, husk and powdered rice were calculated using the same method. The following equation was used to calculate rice yield (Pınar and Beyhan, 1992).

$$RY = \frac{Mk}{Tk} x100$$

RY= Head rice yield, %

MK: Weight of unbroken and broken kernels and bran after milling, gr

TK: Weight of total milled rice, gr.

Rice color and whiteness

Food color is the first parameter of quality evaluated by consumers (Markovic et al., 2013). The color of the milled rice seeds was measured on the basis of the CIE color scales L*, a* and b* using a CM11P digital colorimeter (Figure 2). L* indicates the degree of lightness or darkness of the sample on a scale of 0 (black) to 100 (white), where a low number (0–50) indicates dark and a high number (51–100) indicates light; a* indicates the degree of redness (+a) to greenness (-a), where a positive number indicates red and a negative number indicates green; and b* indicates the degree of yellowness (+b) to blueness (-b), where a positive number indicates yellow and a negative number indicates blue, respectively. The samples were placed in the holder of colorimeter, ensuring that the holder was completely filled with seeds. The measurements were made directly from the top surface of the bulk of the seeds, and the color parameters were measured in 15 replications (Hunter at al.,1987; Zielinska et al., 2012; Markovic et al., 2013; Mir et al., 2013) for each test.

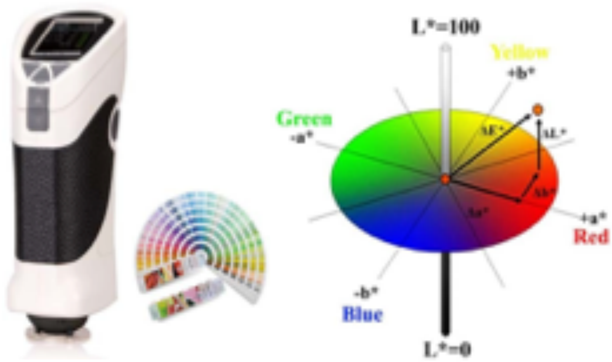

Figure 2. CM11P digital colorimeter

Statistical analysis

The experiment was planned as a complete randomized plot design and data was examined using an analysis of variance (ANOVA) method. Mean separations were made for significant effects with LSD, and the means were compared at 1 % and 5 % levels of significance with Duncan multiple range tests using MSTAT-C software.

RESULTS AND DISCUSSION

Broken kernels, yield and husk quantities

Table 1 reports the changes in the quantities of intact kernel, broken kernel, bran, head rice yield and husk of the paddy threshed at different speeds in the combine harvester, depending on threshing speed, processing time and feed quantity. As the table shows, the cylinder speed used during harvesting had a significant effect on all of the measured parameters ($p<0.01$). Cylinder speed affected the quantity of intact (unbroken) kernels after 850 revolutions per minute. No significant difference was found between 650 and 750 rpm, whereas the quantities of intact kernel obtained at 850, 950 and 1050 rpm were significantly different. The ratio of intact kernels was the highest at 650 rpm, with 67.10 %, and the lowest ratio of 65.75 % was obtained at 1050 rpm, as the highest speed tested. This can be attributed to the strength of the collision impact during threshing. A similar situation was observed in the case of broken kernels. The quantity of broken kernels increased as cylinder speed increased. The ratio of broken kernels varied between 3.633 % and 4.485 %. The quantity of bran, similar to broken kernels, was also higher at higher speeds. The lowest bran ratio was obtained at 650 rpm with 0.680 %, and the highest bran ratio of 1.865 % was obtained from the paddy threshed at a cylinder speed of 1050 rpm. Yield, on the other hand, decreased slightly as the cylinder speed increased, with yields varying between 71.40 % and 70.28 %. This decline can be attributed to the increase in the quantity of broken kernels and the decrease in the quantity of intact kernels at higher cylinder speeds. The same can be said for the quantity of husk, the ration of which was 29.039 % at the lowest cylinder speed of 650 rpm, and decreasing slightly at higher speeds to reach 27.665 % at the highest tested speed (Table 1). The decrease in the quantity of husk was directly related to the increase in the quantity of broken kernels and bran.

Table 1 shows the effects of processing time on the quantities of intact kernel, broken kernel, bran, yield and husk. As the processing time increased, the quantities of broken kernel and bran also increased, while the quantities of intact kernel and yield decreased. The highest proportion of broken kernel was obtained at a processing time of 25 seconds, and the lowest values were obtained at a processing time of 10 seconds. With a processing time of 10 seconds, the quantities of unbroken kernel, broken kernel, bran, yield and husk were 70.74, 3.260, 0.810, 74.37 and 24.82 %, respectively. When the processing time was 25 seconds, the quantity of broken kernel decreased from 70.74 % to 62.86 %, and yield decreased from 74.37 % to 67.58 %. The broken kernel ratio increased from 3.26 % to 4.633 % and bran ratio increased from 0.8642 % to 1.822 %. Husk ratio, on the other hand, increased from 24.82 % to 30.60 %. In other words, as the processing time increased, so did the bran ratio and husk ratio. Kim and Lee (2012) report that the quantity of loss during rice processing varies between 0.58–5.61 %, concurring with the values observed in the present study. After milling, the broken rice grains are often separated from the whole rice grains. Depending on the acceptable level of broken grain allowed by the customer, these broken kernels may then be blended in a precise ratio with the unbroken kernels to maximize the profitability of the mill (Bond, 2004; Buggenhout et al. 2013).

Changes in the quantities of unbroken kernel, broken kernel, bran, yield and husk by feed quantity shows that feed quantity had a significant effect on these values (Table 1). As the feed quantity increased the quantity of unbroken kernels and yield ratio decreased. On the other hand, an increase in feed quantity resulted in statistically significant increases in the quantities of broken kernel and bran. No significant changes were observed in the husk ratio. The lowest unbroken kernel ratio and yield were obtained at a feed quantity of 80 gr, whereas the differences between the other feed quantities were not significant. On the other hand, the highest broken kernel ratio and bran ratio were obtained at this feed quantity, with 4.233 % and 1.721 %, respectively. At feed quantities of 20, 40 and 60 grams, yield did not change, remaining at 71.08 percent, with the lowest yield being 69.87 %. This value is higher than the maximum yield values obtained by Evgi and Ülger (2006) for Baldo and Osmancık paddies, which were 59.9 % and 56.3 %, respectively. Similar findings were also reported by Singha (2012). In a study conducted of 442 paddy processing plants in five states of India, Singha (2013) found that yield varied between 58.6 % and 64 %, depending on the use of either modern or traditional processing methods. Kumar and Kalita (2017) reported theoretical average milling yield of rice for Asian countries of around 71–73 %. The main parameter used to quantify rice dehulling and milling efficiency is the head rice yield (Buggenhout et al. (2013). Andrews et al. (1992), Schluterman and Siebenmorgen, (2007), and Buggenhout et al. (2013) define

Table 1. Variation in intact kernel ratio, broken kernel ratio, bran ratio, rice yield and husk ratio by cylinder speed, processing time and feed quantity.

Parameters	Intact kernel ratio, %	Broken kernel ratio, %	Bran ratio, %	(Yield), %	Husk ratio, %
Cylinder speed, (rpm)					
650	67.10 a	3.633 d	0.680 d	71.40 b	29.039 a
750	66.87a	3.886c	1.011 c	70.95 a	27.769 b
850	66.82 a	4.063 bc	1.454 b	70.94 a	27.596 b
950	66.08b	4.155 b	1.520 b	70.47 a	27.540 b
1050	65.75 b	4.485a	1.865a	70.28 a	27.665 b
LSD	0.5166	0.2261	0.1134	0.611	0.2228
Processing time, (s)					
10	70.74 a	3.260 a	0.810 d	74.37 a	24.82 d
15	67.35 b	4.091 b	1.103 c	71.64 b	27.25 c
20	65.15 c	4.193 c	1.489 b	69.49 c	29.02 b
25	62.86 d	4.633 d	1.822a	67.58 d	30.60 a
LSD	0.5166	0.2022	0.10149	0.547	0.2228
Feed quantity, (g)					
20	67.00 b	3.929 b	0.864 d	71.08 a	28.056 b
40	67.07 b	3.850 b	1.200 c	71.08 a	27.720 b
60	66.66 a	4.165 a	1.439 b	71.06 a	27.500 b
80	65.379 a	4.233 a	1.721 a	69.87 b	28.409 a
LSD	0.5166	0.2022	0.10149	0.547	0.2228

yield as the quantity of kernels that remain after milling. Depending on the type of processing, yield is reported to vary between 0 % and 75 %. In a study conducted by Pınar and Beyhan (1992), the paddy to rice conversion ratio was on average 60.90 percent for rice yield, 8.8 percent for broken rice, 0.8 % for powder (fine) rice, 4.9 % for bran and 24.6 % for husk.

Rice color and whiteness

The whiteness of the threshed paddy was not affected by the increase in cylinder speed, and the differences between the values from different cylinder rotation speeds were found to be insignificant. This was true also for values a and b. No differences were identified at speeds higher than 650 rpm. On the other hand, processing time was found to have a statistically significant effect on the L value, and insignificant effects on the a and b values. As the processing time increased, the whiteness value (L) also increased (Table 2 and Figure 3). The highest whiteness value (L) was obtained at the processing time of 25 seconds with 70.92, and the lowest L value was obtained at the processing time of 10 seconds with 63.81. The effect of feed quantity on color changes, on the other hand, was insignificant for the L, a and b values. In conclusion, of the independent parameters, only processing time had a significant and noticeable effect on color changes, as can be seen in Table 2 and Figure 3.

CONCLUSION

Processing time was found to have a highly significant effect ($p<0.01$) on the quantities of intact kernel, broken kernel, bran, yield and husk. As the processing time increased, so did the bran ratio and husk ratio, whereas yield declined. Yield was 74.37 percent at a processing time of 10 seconds, and the lowest yield of 67.58 percent was obtained at a processing time of 25 seconds. The feed quantity had a lesser effect.

Cylinder speed had an insignificant effect on the color of rice threshed and processed at different speeds, whereas processing time had a highly significant effect on the color parameters. The highest whiteness value of 70.92 was obtained at a processing time of 25 seconds; while the lowest whiteness value of 63.81 was obtained at a processing time of 10 seconds. There were declines in a

Table 2. L, a and b values

Parameters	L: lightness or darkness	a: degree of redness (+a) to greenness (-a)	b: degree of yellowness 5 (+b) to blueness (-b),
Cylinder speed, (rpm)			
650	67.87±0.236483 a	-1.020±0.09385 a	13.11±0.14708 a
750	67.86±0.236483 a	-1.474±0.09385 b	12.38±0.14708 bc
850	67.57±0.236483 a	-1.383±0.09385 b	12.53±0.14708 b
950	67.73±0.236483 a	-1.457±0.09385 b	12.09±0.14708 c
1050	67.46±0.236483 a	-1.368±0.09385 b	12.14±0.14708 bc
LSD	0.6606	0.2621	0.4109
Milling time, (s)			
10	63.81±0.21152 d	-0.690±0.083948 ns	15.01±0.13155 ns
15	67.15±0.21152 c	-1.279±0.083948 ns	13.00±0.13155 ns
20	68.92±0.21152 b	-1.660±0.083948 ns	11.50±0.13155 ns
25	70.92±0.21152 a	-1.732±0.083948 ns	10.31±0.13155 ns
LSD	0.5906	0.2345	0.3675
Feed quantity, (g)			
20	67.68±0.21152 b	-1.375±0.083948 ns	12.186±0.13155 ns
40	67.22±0.21152 b	-1.390±0.083948 ns	12.523±0.13155 ns
60	68.38±0.21152 a	-1.319±0.083948 ns	12.441±0.13155 ns
80	67.52±0.21152 b	-1.275±0.083948 ns	12.660±0.13155 ns
LSD	0.5906	0.2345	0.3675

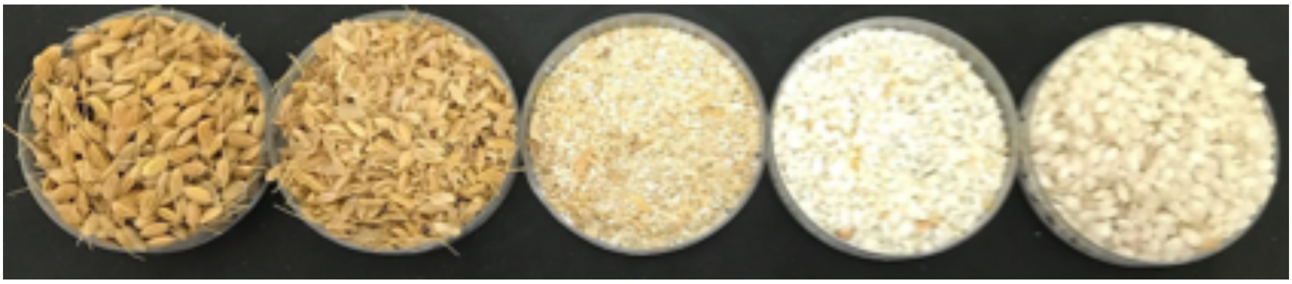

Figure 3. Rice color changes at different milling times.

and b values as processing time increased, although the differences were not statistically significant. The highest a and b values were obtained at a processing time of 10 seconds, with -0.690 and 15.01, respectively. In conclusion, when processing paddy to rice, processing time needs to be increased to obtain a whiter rice; to have fewer broken kernels and a higher yield, on the other hand, the processing time needs to be short.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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