INFLUENCE OF OPERATING PARAMETERS ON THE MILLING QUALITY OF LONG-GRAIN WHITE RICE

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تأثير عوامل التشغيل على جودة الضرب للأرز طويل الحبة

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***Keywords:** Broken rice percentage; Milling process; Head rice yield; Whitening degree*

ABSTRACT

The current study aimed to test and evaluate sheets' different perforation shapes, brake angles, and milling durations to improve the quality of long-grain white rice from an abrasive milling machine. The investigated parameters of head rice yield, broken rice percentage, whitening degree, and rice bulk temperature were influenced by five sheets with five perforated shapes (horizontal, vertical, inclined, 1 mm round holes, and 1.5 mm round holes), three brake angles (0, 45, and 90º), and four milling durations (60, 70, 80, and 90 s). The results showed that the horizontal rectangular perforated sheet resulted in the highest value of head rice yield and the lowest value of broken rice. On the other hand, the vertical rectangular perforated sheet resulted in the highest whitening degree, followed by the inclined rectangular perforated sheet. The round holes (1.0 mm and 1.5 mm diameter) are not recommended for the long-grain whitening process because of the resulting high values of broken kernels, rice bulk temperature after the whitening process, and lower values of whitening degree. The brake angle of 90º resulted in the highest value of broken rice for all studied perforated sheets used in this study. This study recommended that the optimum operating conditions were using the horizontal rectangular perforated sheet, zero degree brake angle and milling duration of 80 s.

الملخص

تهدف الدراسة الحالية إلى اختبار وتقييم شبكات التبييض ذات اشكال الثقوب المختلفة وزوايا الفرامل وفترات الطحن المختلفة لتحسين جودة الضرب للأرز الأبيض طويل الحبة. تناولت هذه الدراسة تاثير كلا من شبكات تبييض ذات خمس أشكال للثقوب (أفقية، رأسية، مائلة، ثقوب دائرية 1 مم، وفتحات دائرية 1.5 مم)، وثلاث زوايا فرامل (0، 45، 90 درجة) وأربع فترات طحن (60، 70، 80، 90 ثانية) على نسبة الأرز السليم، ونسبة الأرز المكسور، ودرجة التبييض، ودرجة حرارة الأرز. أظهرت النتائج أن الشبكة المثقبة الأفقية المستطيلة أظهرت أعلى قيمة للأرز السليم وأدنى قيمة الأرز المكسور. وعلى الجانب الأخر، نتج عن الشبكة المثقبة المستطيلة الرأسية أعلى درجة تبييض، تليها الشبكة المثقبة المستطيلة المائلة. لا ينصح باستخدام الشبكات ذات الثقوب المستديرة (باقطار 1.0 مم و 1.5 مم) لعملية التبييض للأرز طويل الحبة بسبب القيم العالية الناتجة للحبوب المكسورة ودرجة حرارة كتلة الأرز بعد عملية التبييض والقيم المنخفضة لدرجة التبييض. أدت زاوية الفرامل البالغة 90 درجة إلى الحصول على أعلى قيمة للأرز المكسور لجميع أشكال الشبكات المثقبة المستخدمة في هذه الدراسة. أوصت هذه الدراسة بأن ظروف التشغيل المثلى كانت باستخدام الشبكة المثقبة الأفقية المستطيلة وزاوية الفرملة الصفرية ومدة الطحن 80 ثانية

INTRODUCTION

Rice (*Oryza sativa* L.) is presently the world's most important cereal grain, with one-fourth of the population depending on it as major stable food. By 2050, rice demand is expected to double as the global population grows (*Ray et al., 2013*), especially after the shortage of wheat supply chains caused by the Russian-Ukrainian war. Egypt is one of the world's major rice-producing countries, producing about 4,893,507 Mg (*FAOSTAT, 2020*). Rice production has expanded in recent years to meet the rise in human demand. Paddy (rough) rice includes two layers that cover a rice kernel; the inner layer is the bran, and the outer layer is the hull or husk. The husk is inedible, and bran diminishes the rice luster; hence, they must be removed from the paddy. The rice milling process is defined as removing the rice kernel's husk (hulling) and bran layer (polishing), making the rice edible (endosperm) and free from impurities. In addition, the milling process is

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essential because it enhances rice's nutritional, cook time, and sensory qualities (*Dhankhar, 2014*). Rice milling is a routine practice for the post-harvest processing of rice grains. Still, broken rice production during milling is an inescapable and global problem (*Zeng et al., 2022*). Moreover, rice milling plays a key role in determining rice quality, and assessing the appearance quality is an efficient method to differentiate the milling degree (*Ren et al., 2021*).

Most consumers in Egypt prefer well-milled rice with no bran remaining on the endosperm; thus, this procedure must be carried out carefully to prevent extreme kernel breakage and to promote paddy recovery. Consequently, great benefits will be gained by reducing the broken rice rate in white rice during rice milling. Losses during the milling process are classified as quantitative and qualitative losses. Quantitative or physical losses are manifested by low milling recovery.

In contrast, qualitative losses are manifested by a high percentage of broken grains or low head rice recovery in the milled product, especially in long-grain varieties, because of their low hardness compared to short-grain varieties (*Radwan, 2001*). Head rice yield (HRY) often differs from the moisture content (MC) at which rice is harvested (*Siebenmorgen et al., 2007*). Furthermore, many factors influence HRY during the milling process, including preharvest weather conditions, grain moisture content at harvest, techniques of paddy drying, alterations in grain moisture content after drying, storage conditions for paddy, and milling equipment (*Abayawickrama et al., 2017*).

Drying is a post-harvest process that greatly affects rice milling yield and overall quality by lessening paddy rice's moisture content to an appropriate level. Rice's moisture content should be lowered from 22 to 14% at harvest to roughly 13% for storage to diminish the rates of respiration and mold growth and inhibit fungi and insect growth. In fact, milling caused some kernels to break, even in rice lots that have been harvested, dried, and stored with intense care (*Mukhopadhyay and Siebenmorgen, 2018*). In the same trend, rough paddy grains must be dried to a moisture content below 14% (w.b.) for safe storage, whereas the optimal moisture content of paddy for milling remains between 13% and 14% (w.b.) (*IRRI, 2013*). In addition, rice kernels are subjected to intensive thermal and mechanical stresses during milling, which might break or damage some kernels. Some parameters, such as the paddy characteristics, whitening machine type, and environmental factors, influence the rice kernel breakage and damage during the milling process (*Afzalinia et al., 2004*).

Removing all the bran in one whitening operation leads to significant breakage and decreases total rice recovery. Hence, most modern rice mills use multi-pass whiteners because multi-pass whitening produces higher rice mill recovery, increasing head rice yield and reducing broken rice percentage. Therefore, some systems were suggested to get the best rice quality (*Tangpinijkul, 2010*). Using three abrasive-type whiteners with a friction whitener as a polisher kept the minimum breakage of rice and the least milling cost, and its output kept the most acceptable appearance and marketability (*Afzalinia et al., 2004*). Head rice yield (HRY) for long and extra-long grain rice was higher with abrasive milling (61–75%) compared to friction milling (10–60%) (*Kalpanadevi et al., 2019*). Thus, it was the most effective rice milling system for the tested variety and region.

A Satake whitening machine model TM–05 was used to white medium-grain (Mutsuhonami variety) using four rotor speeds (810, 1020, 1310, and 1500 rpm, respectively) for a 40 s whitening period. The results reported that a rotor speed of 810 rpm resulted in under-milling, whereas a rotor speed of 1500 rpm resulted in over-milling (*Bekki and Kunze, 1988*).

Long and tiny rice kernels were more susceptible to breakage than wide short kernels during milling (*Seguy and Clement, 1994*). The milling duration has an effective effect; an increase in duration increases the milling degree and which in turn reduces the head rice yield (*Puri et al., 2014*). In the same trend, Eliçin et al. (2022) studied the influence of rice milling duration on head rice yield (HRY), and their results revealed that rice milling duration is a crucial factor in head rice yield, where increasing the rice milling time from 10 to 25 s decreased the head rice yield by 9.13%. Matthews et al. (1970) evaluated the breakage for both medium-grain and long-grain rice. The results revealed that most breakages ensued in the first 10 s of milling. Removing the bran continued at a decreasing rate throughout the milling duration. The polishing duration could be extended to around 150 s without increasing breakage significantly over that which occurred in the first 10 s of the milling duration. Also, approximately 65 to 73% of the bran was removed in the first 20 s of the milling period for all tested varieties (four long-grain varieties and one medium-grain variety). The rate of bran removal was as much as 4 times higher in the first 20 s than in the next 20 s of the milling period (*Velupillai and Pandey, 1987*). Moreover, excessive milling increases energy consumption (*Ahmad et al., 2017*).

The horizontal whitening machine was developed in Japan after World War II and is well-appropriate to the short-grain Japanese rice varieties. Nevertheless, its introduction in Asia and other Far East countries has been delayed because sensitive adjustments are necessary to acclimate medium and long-grain varieties (*Soepardjo, 1981*).

Thus, from that time until now, many researchers and investigators have worked on this machine to improve its efficiency and long-grain white rice quality. Therefore, this study aimed to improve long-grain white rice quality by reducing broken rice percentage and increasing the whitening degree and head rice yield by suggesting some shapes of perforated sheets and milling durations to suit the long-grain rice variety in Egypt.

MATERIALS AND METHODS

Rice crop

Egyptian long-grain rice *Indica* type (Giza 181 variety), freshly harvested with an average moisture content of 16% (w.b.), was used in this experiment. The laboratory trials were carried out at the laboratory of Rice Mechanization Center (RMC), Kafr El-Sheikh, Egypt. The rice samples were cleaned of impurities, immature kernels, and foreign materials and stored at 1 ºC in a cooler to avoid moisture loss. At the beginning of the experiment, rough rice samples were taken from the cooler and mixed manually. The samples were dried under shade to the desired moisture content suitable for hulling and whitening (14% ± 0.5% w.b.).

The rice hulling machine

The rubber roll huller Yanmar (model ST–50) was used in this study to hull paddy rice samples and get brown rice for the whitening experiments. The huller comprises two rubber rolls with diameters and lengths of 110Ø × 50 mm, respectively. One has a fixed position, and the other is adjustable to get the desired clearance between the two rolls. The clearance between the two rolls was adjusted to be 2/3 the thickness of the grain (*Radwan, 1994*). The grain feed rate of 1 kg min^{-1} was kept constant, and when the rough rice was fed between the two rolls and then caught under rubber pressure, the husk was stripped off. The resulting brown rice was separately discharged in receptacles and collected in a pan for whitening. The huller was manually cleaned of trapped grains before and after the hulling of each sample.

The rice whitening machine

In this experiment, Satake whitening laboratory machine (model TM–05, Satake Co., Tokyo, Japan) was used to polish the brown rice resulting from the hulling machine. The machine has a capacity of 0.2 kg and a 0.4 kW built-in motor, and it comprises an abrasive roll (emery stone) operating in a cylindrical metal perforated screen. The brown rice fed into the free space between the perforated sheet and the abrasive roll. The abrasive operation removes the bran layers from the grain to produce white rice.

The perforated sheets

The perforated sheets keep the rice grains in contact with the stone's surface, thus allowing bran separation, and, at the same time, its rough surface helps peel the bran layer by friction. Wire netting with suitable mesh size and wire diameter, if compared to the perforated sheets, provides more effective abrasive action and allows more space for the bran to pass through. On the other hand, the perforated sheets reduce the risk of breaking the grains; thus, both materials have advantages and disadvantages (*FAO, 1981*).

In the horizontal whitening machine, three rows of adjustable steel brakes are installed over the cylindrical housing length that can be adjusted from zero to 90 (radial). These adjustable brakes direct the position of the rice grain inside the machine during the whitening process to get optimum whitening efficiency. The optimal brake change angle depends on the variety of rice being processed. This point remains crucial in the machine's operation, which requires an experienced operator. When the inclination is set at zero degree, the resistance pieces give minimum resistance and minimum thrust to the moving grain so that the grain moves along the direction of the slots. When the inclination is set at 45°, the resistance pieces give maximum thrust and medium resistance to the grain. When the inclination is set at 90°, the resistance pieces give maximum resistance but no thrust to the moving grain (*Satake, 1983*).

Rice whitening trial

Five sheets with five perforation shapes (two round holes with diameters of 1.0 mm and 1.5 mm and three rectangular perforations, namely horizontal, vertical, and inclined rectangular with dimensions of 25 mm length and 1.5 mm width, as shown in Figs. 1 and 2, four whitening durations (60, 70, 80, and 90 s) and three steel brake angles (0, 45, and 90º) were used in this study. Samples of 150 grams each were processed in one pass (Satake, 1992). All the milled rice grains were carefully removed from the machine and collected in a pan to determine the temperature of the resulting white rice immediately. The broken rice was separated from the head rice and weighted. The head rice portions were taken for color analysis. The whitening machine was manually cleaned of trapped grains before and after processing each sample.

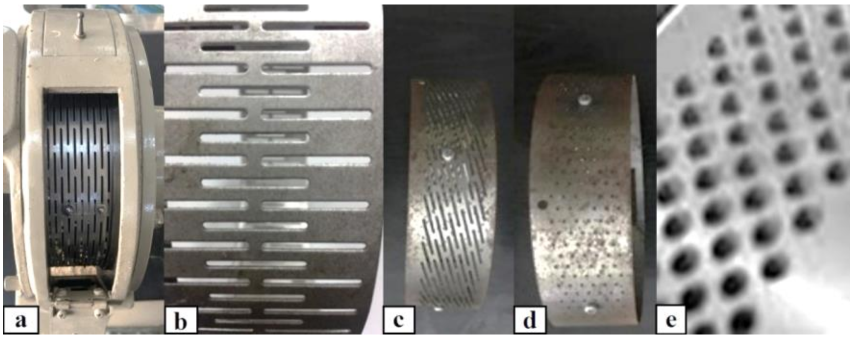


Fig. 1 – Sheets with different perforations shapes *(a) the horizontal rectangular sheet (parallel to rice direction), (b) the vertical rectangular sheet (perpendicular to rice direction), (c) the inclined rectangular sheet, (d) round holes 1.0 mm, and (e) round holes 1.5 mm*

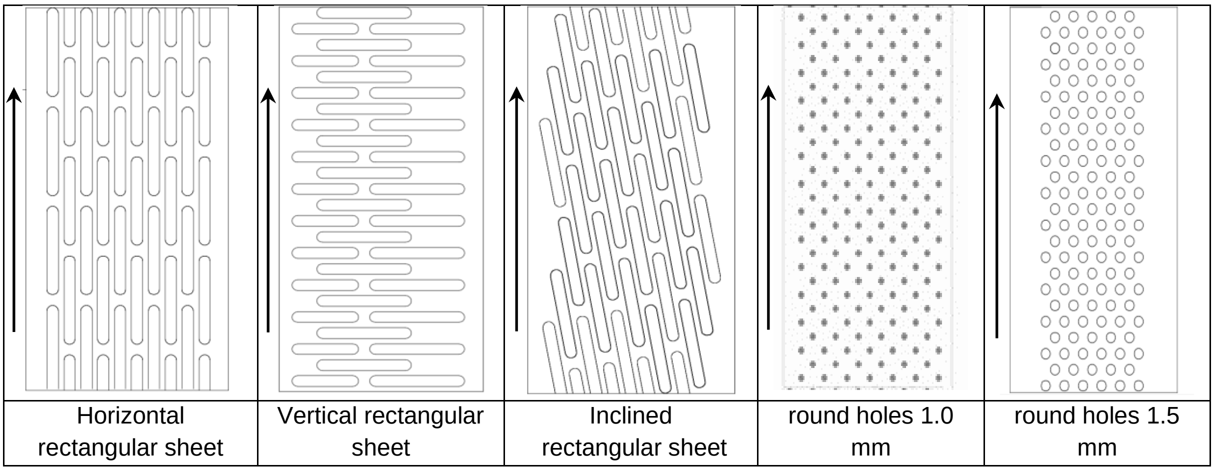


Fig. 2 – The different perforated sheets used for the whitening machine (arrow refers to rice direction)

Measurements

Measurements of rice's dimensions, moisture content, and temperature

One hundred rice grains were randomly selected from the tested variety in this study to determine the mean grain dimensions (length "L", width "W" and thickness "Th"). The mean dimensions were measured by a digital caliper. The paddy sample's moisture content (MC) was determined using a 25 g paddy sample placed in an air oven at 130º C for 16 h (*Matouk et al., 2000*). The resulting moisture content represents the average of three replicates. The bulk temperature of the rice was immediately determined at the end of each trial. The discharged white rice was received in an insulated glass cylinder. A digital multimeter model (A.W. SPERRY DM–8600) with a temperature range from -30 to 400 °C and +0.5% accuracy was used to measure a one-point temperature. The meter prop (K–type thermocouple) was inserted through the rice bulk until reaching a constant reading.

Measurements of milling quality

In order to determine the milling quality of each sample, three calibration parameters were considered, i.e., head rice yield, broken rice percentage, and whitening degree (*Siebenmorgen, et al., 2006*).

a. Head rice yield (HRY)

The head yield is defined as the mass percentage of rough rice that remains head rice after milling (*Siebenmorgen, et al., 2006*). The milled grain that is three-quarters or larger than its original size is considered a whole grain (*Egyptian Standard, 1992*).

b. Broken rice percentage

The broken percentage was calculated in Eq. (1), according to (*Gbabo and Ndagi, 2014*).

$$P = \frac{W_b}{W_s} \cdot \omega \tag{1}$$

where P is the broken percentage, [%]; W_b is the weight of the broken kernels, [g]; and W_s is the total weight of the sample, [g.]

c. Whitening degree

A digital whiteness meter (model C–300, Kett Electric Co., Japan) with a resolution of 0.1% and measuring range of 5–70 was used to measure the whitening degree of milled rice for each treatment.

The measuring principle for this meter depends on the amount of reflected light from the whitened rice surface (photo-diode).

Statistical analysis

Analysis of variance (ANOVA) was done to determine the influence of perforated sheet shape, milling duration, and brake angle on all the dependent variables. The regression analysis was also done to get some relationships between the parameters, and the regression equations are shown in Figs. 3–6 in the results and discussion section.

RESULTS AND DISCUSSION

Grain dimensions

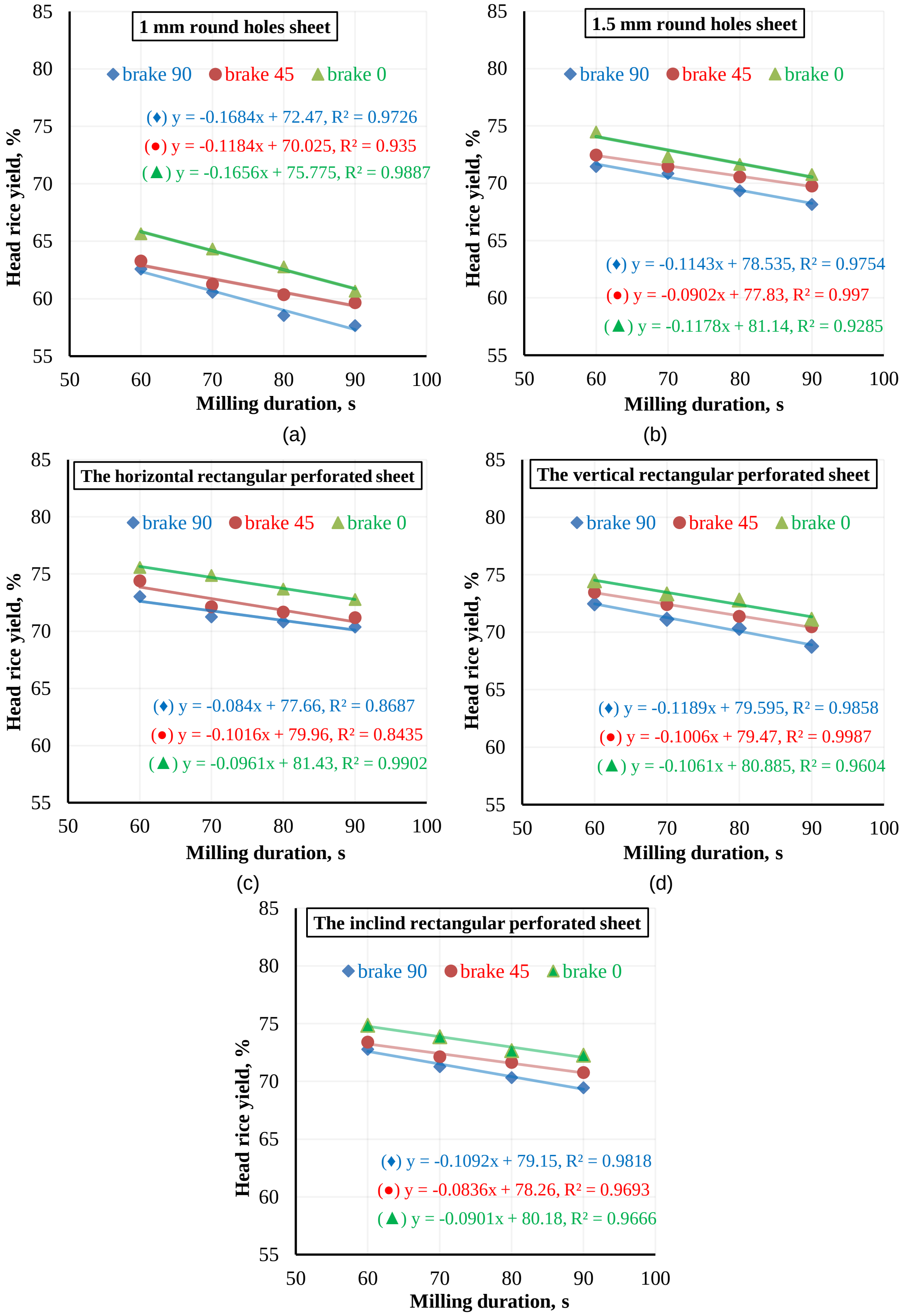
The results of one hundred rice grains from the Egyptian long-grain variety (Giza 181) chosen for the study showed that the mean grain dimensions (length “L”, width “W” and thickness “Th”) were 9.28, 2.52, and 2.02 mm, respectively. The corresponding results for the brown rice grain were 7.42, 2.32, and 1.76 mm, respectively. These results were used to adjust the clearance of the huller machine to obtain a good efficiency of the huller and help select the perforated sheet suit for long-grain rice varieties.

Effect of sheets’ different perforations shapes, brake angles, and milling durations on head rice yield

Five sheets with five perforation shapes were suggested and evaluated to recommend the optimum one for improving long-grain rice quality in terms of head rice yield, broken rice percentage, and whitening degree. Fig. 3 shows the effects of the sheets’ different perforation shapes, brake angles, and milling durations on head rice yield. As shown in the figure, in case of using a 1.0 mm round holes sheet resulted in recording the lowest head rice yields (57.66, 58.54, 60.56, and 62.60%) at 90º brake angle and milling durations of 90, 80, 70, and 60 s, respectively, followed by 1.5 mm round holes. This result may be attributed to the thin rice kernels sometimes lining up in the holes and causing them to break. On the other side, the highest head rice yields (75.57, 74.88, 73.67, and 72.77%) were obtained by using the horizontal rectangular perforated sheet (parallel to the rice direction) at zero degree brake angle and the same milling durations, respectively, followed by the inclined rectangular perforated sheet and the vertical rectangular perforated sheet at the same brake angle. The statistical analysis showed that the perforated sheet shape significantly affected the head rice yield.

Regarding the effect of brake angle on head rice yield, it can also be seen in Fig. 3 that increasing the brake angle from zero to 90º decreases the head rice yield at all shapes of perforated sheets and milling durations under this study. Increasing brake angle from zero to 90º decreased head rice yield from 65.66–62.60%, 74.47–71.47%, 75.57–73.02%, 74.47–72.47%, and 74.87–72.78% at 60 s milling duration for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively.

Involving the effect of milling duration on head rice yield, as shown in Fig. 3, increasing milling duration decreased head rice yield for all perforated sheets and brake angles. Where increasing the milling duration from 60 to 90 s, decreased head rice yield from 65.66–60.66%, 74.47–70.77%, 75.57–72.77%, 74.47–71.11, and 74.87–72.27% at zero brake angle for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively.



(e)

Fig. 3 – Effect of milling durations, brake angles and sheets' different perforations shapes

(a) 1 mm round holes sheet, (b) 1.5 mm round holes sheet, (c) the horizontal rectangular sheet, (d) the vertical rectangular sheet, (e) the inclined rectangular sheet on head rice yield

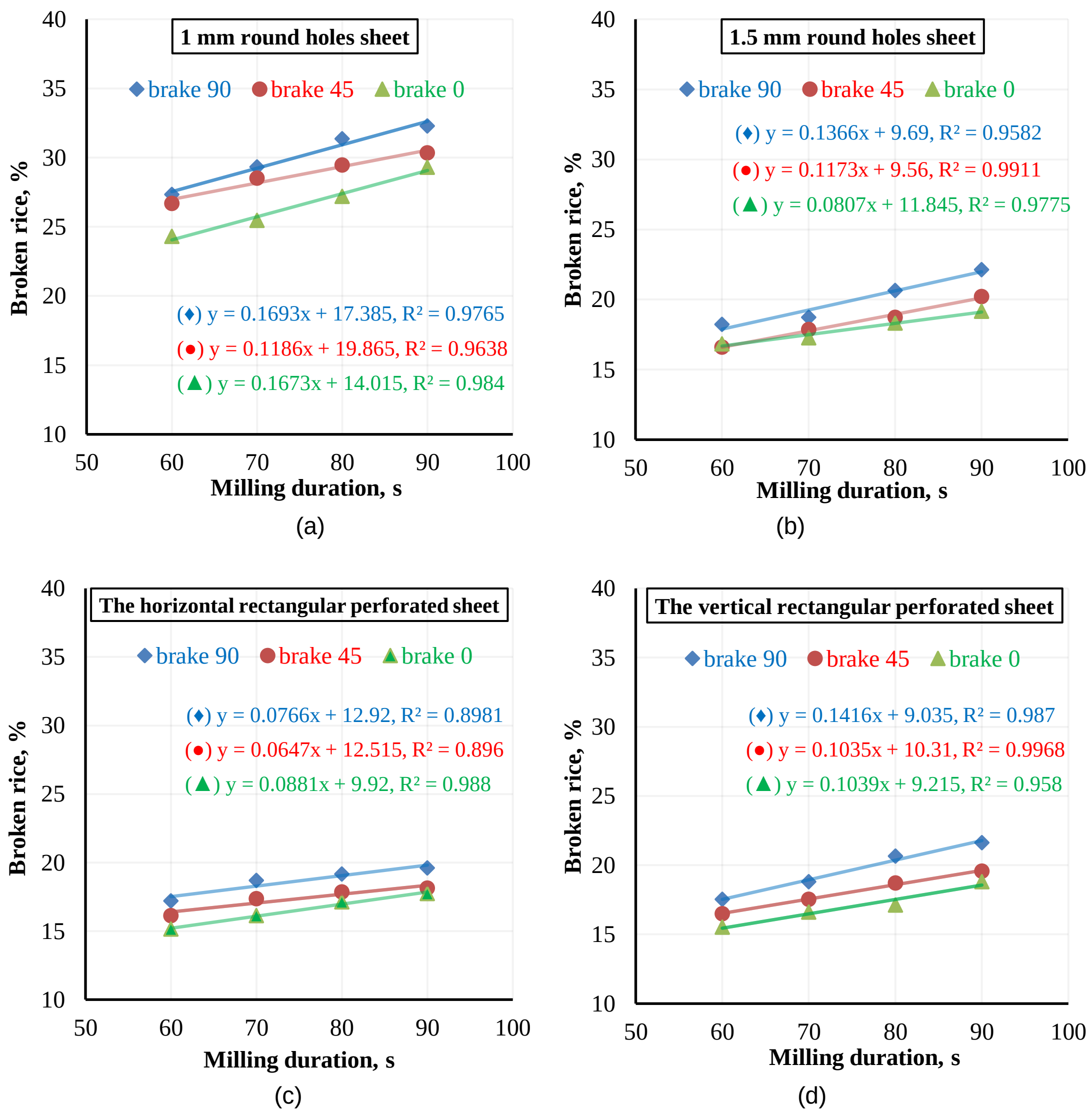
Effect of sheets' different perforations shapes, brake angles, and milling durations on broken rice percentage

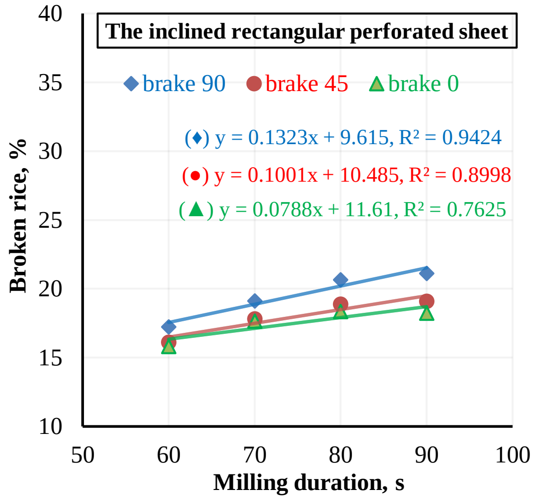
Fig. 4 shows the effect of perforated sheet shape on broken rice percentage. As shown in the figure, in the case of using a 1 mm round holes sheet resulted in obtaining the highest percentage of broken rice (32.30, 31.36, 29.34, and 27.33%) at 90º brake angle and milling durations of 90, 80, 70, and 60 s, respectively, followed by 1.5 mm round holes sheet at the same brake angle. On the other hand, using the horizontal rectangular perforated sheet resulted in recording the lowest percentages of broken rice (17.73, 17.13, 16.12 and 15.13%) at zero degree brake angle and milling durations of 90, 80, 70, and 60 s, respectively, followed by the inclined rectangular perforated sheet and the vertical rectangular perforated sheet. The statistical analysis revealed that the effect of perforated sheet shape on broken kernels percentage was highly significant.

Concerning the effect of brake angle on broken rice percentage, Fig. 4 reveals that increasing brake angle increased broken rice percentage at all shapes of perforated sheets and milling durations. Increasing brake angle from zero to 90° increased broken rice percentage from 24.30–27.33%, 16.83–18.22%, 15.13–17.20%, 15.51–17.53%, and 15.83–17.23% at 60 s milling duration for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively.

Relating the effect of milling duration on broken rice percentage, as shown in Fig. 4, increasing milling duration increased broken rice percentage for all perforated sheets and brake angles. Where increasing the milling duration from 60 to 90 s, increased broken rice percentage from 24.30–29.30%, 16.83–19.17%, 15.13–17.73%, 15.51–18.80, and 15.83–18.23% at zero brake angle for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively.

In addition, Fig. 4 shows that most of the rice breakage occurred in the first 60 s of the milling process for all the perforated sheets and brake angles, but the whitening process could not be finished because the white rice's appearance was not good yet.





(e)

Fig. 4 – Effect of milling durations, brake angles and sheets' different perforations shapes
(a) 1 mm round holes sheet, (b) 1.5 mm round holes sheet, (c) the horizontal rectangular sheet, (d) the vertical rectangular sheet, (e) the inclined rectangular sheet on broken rice percentage

Effect of sheets' different perforations shapes, brake angles, and milling durations on rice whitening degree

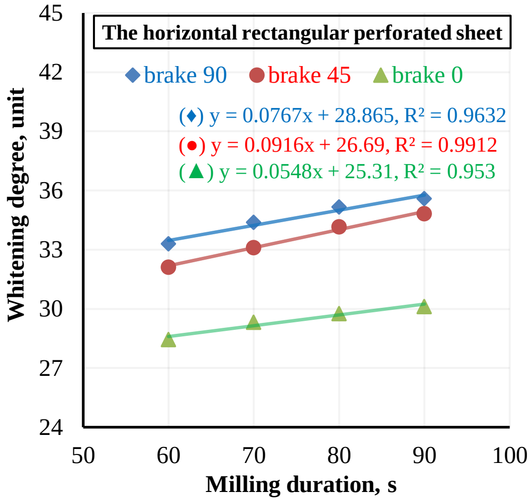
Fig. 5 illustrates the influence of the different perforated sheet shapes on the rice whitening degree. As depicted in the figure, using a sheet with 1 mm round holes yielded the lowest levels of whitening at all milling durations and brake angles. Where the lowest levels of whitening were 27.77, 26.57, 25.77, and 25.23 unit, recorded at zero degree brake angle and milling durations of 90, 80, 70, and 60 s, respectively, followed by the horizontal rectangular perforated sheet. This could be attributed to the difficulty of rice bran passing through the small holes of the perforated sheet, making the whitening process difficult. Contrary to this, the vertical rectangular perforated sheet resulted in the highest values of whitening degree (38.70, 38.40, 37.73, and 37.12 unit) at 90° brake angle and milling durations of 90, 80, 70, and 60 s, respectively, followed by the inclined rectangular perforated sheet and 1.5 mm round holes sheet.

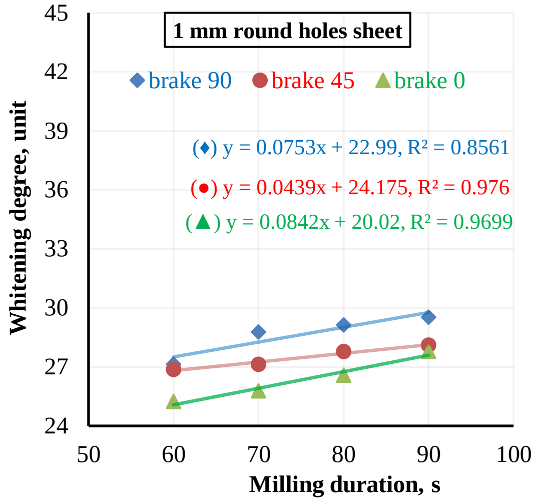
The statistical analysis indicated that the effect of the perforated sheet shape is highly significant on the whitening degree for all the parameters under study.

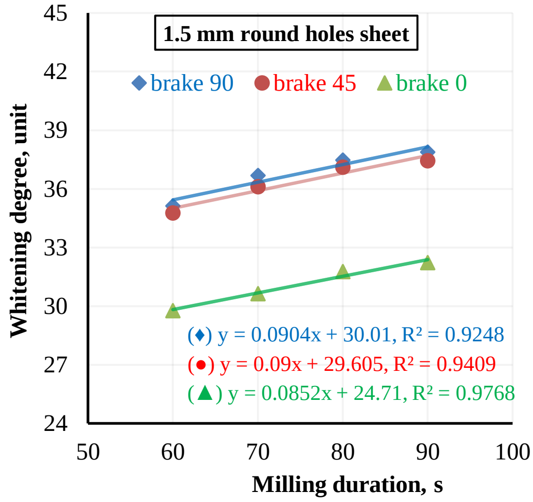
Regarding the effect of brake angle on whitening degree, it can also be seen in Fig. 5 that increasing the brake angle from zero to 90° increased the whitening degree at all shapes of perforated sheets and milling durations. Increasing brake angle from zero to 90° increased the whitening degree from 25.23–27.13 unit, 29.77–35.13 unit, 28.45–33.30 unit, 31.45–37.12 unit, and 32.57–36.35% at 60 s milling duration for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively. The 90º brake angle is recommended compared to zero degree, in the case of whitening degree only, because the angle of 90º yielded a good appearance of white rice. The choice between 90º and 45º brake angle depends upon the choice between the lowest broken rice percentage and the good appearance of white rice.

Concerning the effect of milling duration on whitening degree, as shown in Fig. 5, increasing milling duration increased the whitening degree for all perforated sheets and brake angles. Where increasing the milling duration from 60 to 90 s, increased whitening degree from 25.23–27.77 unit, 29.77–32.23 unit, 28.45–30.13 unit, 31.45–33.13 unit, and 32.57–34.55% at 60 s milling duration for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively.

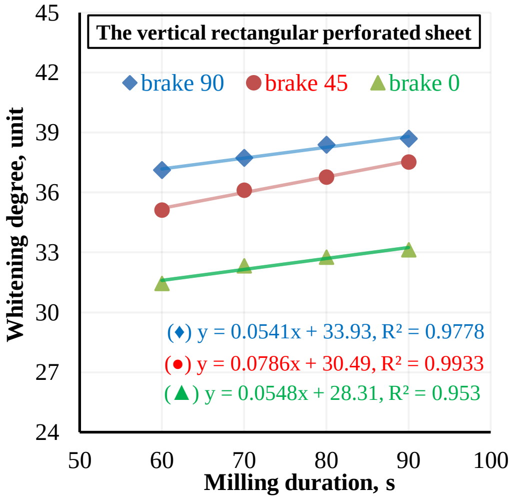
Furthermore, Fig. 5 reveals that the whitening process could continue until the 80 s because the appearance of white rice seems so good now. In addition, there is no difference in the whitening degree for white rice at 80 s and 90 s and at a brake angle of 90º, where the whitening degrees were 38.40 and 38.70 unit for the vertical rectangular perforated sheet, 38.15 and 38.46 unit for the inclined rectangular perforated sheet, 37.47 and 37.88 unit for 1.5 mm round holes, and 35.17 and 35.60 unit for the horizontal rectangular perforated sheet. This means that the 80 s whitening duration is enough to get high-quality white rice with less broken rice percentage compared to the 90 s whitening duration, which may take more power without significant improvement in the quality of the resulting rice.


The horizontal rectangular perforated sheet
brake 90
brake 45
brake 0
(♦) y = 0.0767x + 28.865, R² = 0.9632
(●) y = 0.0916x + 26.69, R² = 0.9912
(▲) y = 0.0548x + 25.31, R² = 0.953
Whitening degree, unit
Milling duration, s
45
42
39
36
33
30
27
24
50
60
70
80
90
100

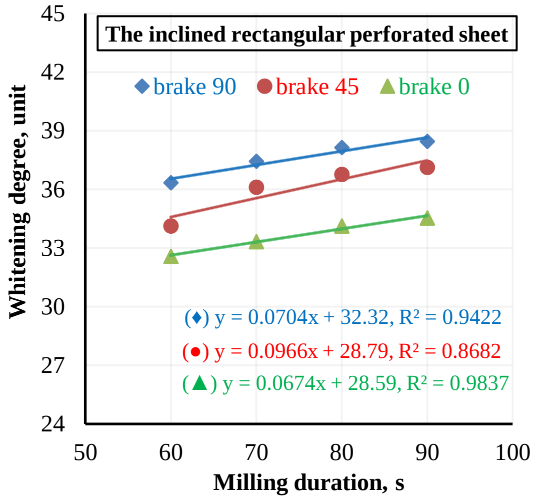

1 mm round holes sheet
brake 90
brake 45
brake 0
(♦) y = 0.0753x + 22.99, R² = 0.8561
(●) y = 0.0439x + 24.175, R² = 0.976
(▲) y = 0.0842x + 20.02, R² = 0.9699
Whitening degree, unit
Milling duration, s
45
42
39
36
33
30
27
24
50
60
70
80
90
100


1.5 mm round holes sheet
brake 90
brake 45
brake 0
(♦) y = 0.0904x + 30.01, R² = 0.9248
(●) y = 0.09x + 29.605, R² = 0.9409
(▲) y = 0.0852x + 24.71, R² = 0.9768
Whitening degree, unit
Milling duration, s
45
42
39
36
33
30
27
24
50
60
70
80
90
100

(a) (b)


The vertical rectangular perforated sheet
brake 90
brake 45
brake 0
(♦) y = 0.0541x + 33.93, R² = 0.9778
(●) y = 0.0786x + 30.49, R² = 0.9933
(▲) y = 0.0548x + 28.31, R² = 0.953
Whitening degree, unit
Milling duration, s
45
42
39
36
33
30
27
24
50
60
70
80
90
100

(c) (d)



(e)

Fig. 5 – Effect of milling durations, brake angles and sheets' different perforations shapes

(a) 1 mm round holes sheet, (b) 1.5 mm round holes sheet, (c) the horizontal rectangular sheet, (d) the vertical rectangular sheet, (e) the inclined rectangular sheet on whitening degree

Effect of sheets' different perforations shapes, brake angles, and milling durations on white rice bulk temperature

The effect of perforated sheet shape on the white rice bulk temperature is shown in Fig. 6. The obtained data revealed that using a sheet with 1 mm round holes resulted in the highest rice temperatures (32.73, 32.32, 31.13, and 30.15 ºC) at 90° brake angle and milling durations of 90, 80, 70, and 60 s, respectively. The high temperatures could be attributed to the high friction caused by the jam of brown rice and bran, which could not pass through the small holes of the perforated sheet. This jam and high temperature explain the low rice quality in terms of highly broken percentage and low whitening degree when using this shape of perforated sheet. On the opposite side, using the horizontal rectangular perforated sheet resulted in the lowest rice temperatures (29.13, 28.15, 27.55, and 26.45 ºC) followed by a 1.5 mm round holes sheet at the same levels of milling duration and zero degree brake angle.

Regarding the effect of brake angle on rice bulk temperature, Fig. 6 shows that increasing the brake angle from zero to 90° increased rice bulk temperature at all shapes of perforated sheets and milling durations. Increasing brake angle from zero to 90° increased rice bulk temperature from 29.25–30.15 ºC, 27.33–28.25 ºC, 26.45–27.65 ºC, 28.65–29.65 ºC, and 28.25–29.85 ºC at 60 s milling duration for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively. Furthermore, statistical analysis revealed that the brake angle significantly affected white rice bulk temperature. The gradients in rice bulk temperature explain the effect of friction action between rice grains and both the whitening stone and the perforated sheet beside the grains themselves. Whenever the rice bulk temperature rises causes increased exposure to thermal stress and easily breaks during the whitening process.

Concerning the effect of milling duration on rice bulk temperature, Fig. 6 illustrates that increasing the milling duration increased rice bulk temperature at all shapes of perforated sheets and milling durations. Increasing the milling duration from 60 to 90 s, increased rice bulk temperature from 29.25–31.55 ºC, 27.33–29.35 ºC, 26.45–29.13 ºC, 28.65–30.55 ºC, and 28.25–30.55 ºC at 60 s milling duration for 1 mm round holes, 1.5 mm round holes, horizontal, vertical, and inclined sheets, respectively. In addition, statistical analysis showed that the milling duration significantly affected white rice bulk temperature.

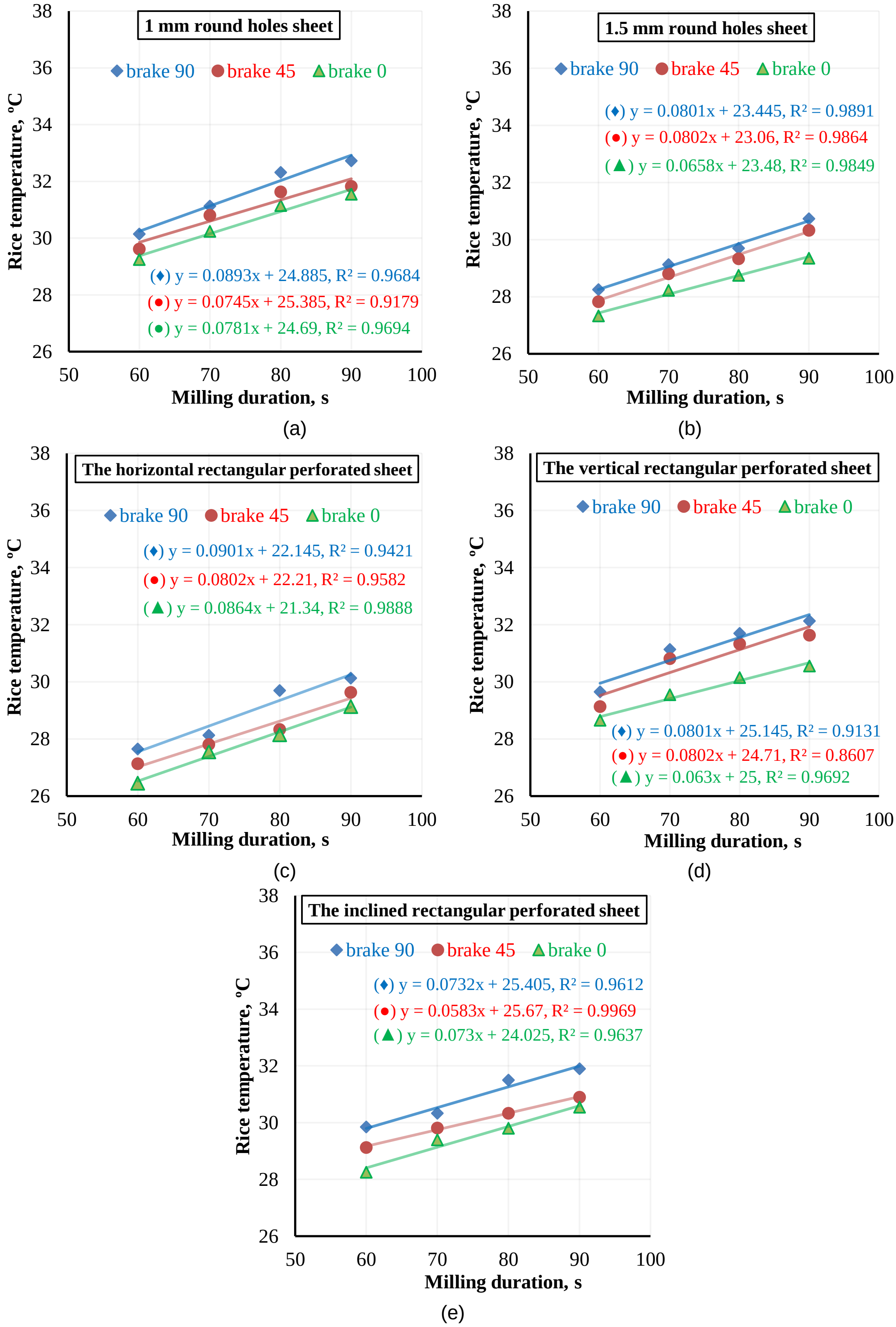


Fig. 6 – Effect of milling durations, brake angles and sheets' different perforations shapes

(a) 1 mm round holes sheet, (b) 1.5 mm round holes sheet, (c) the horizontal rectangular sheet,
(d) the vertical rectangular sheet, (e) the inclined rectangular sheet on rice bulk temperature

CONCLUSIONS

The study aimed to test and evaluate five shapes of perforated sheets, three brake angles, and four milling durations to enhance the quality of long-grain white rice resulting from an abrasive milling machine. The results revealed that using a 1 mm round holes sheet resulted in the lowest head rice yields, the highest percentage of broken rice, the highest rice temperature, and the lowest values of whitening degree at all milling durations and brake angles. The best head rice yields and lowest percentage of broken rice were obtained using the horizontal rectangular perforated sheet at zero degree brake angle followed by the inclined rectangular perforated sheet. The vertical rectangular perforated sheet resulted in the highest values of the whitening degree at all milling durations and 90º brake angle, followed by the inclined rectangular perforated sheet. The horizontal rectangular perforated sheet resulted in the lowest rice temperature, followed by a 1.5 mm round holes sheet at all milling durations and zero degree brake angle. Most of the kernel breakage occurred during the first 60 s, but the processing could not be finished because the appearance of white rice was not good yet. Therefore, the processing could be continued for at least 80 s to get a good appearance of white rice. The brake angle of 90º resulted in the highest broken rice percentage for all studied perforated sheets used in this study. Thus, based on our priorities, the horizontal rectangular perforated sheet is recommended due to its ability to record the highest head rice yield and the lowest broken rice percentage and temperature; it also accomplished an acceptable whitening degree.

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