精米機의 能率에 미치는 機械的要因 및 作動條件에 關한 研究

Mechanical and Operational Factors Affecting the Efficiency of Rice Polishing Machines.

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Summary

In analyzing the operational characteristics of a rice whitening machine, the internal radial pressure of the machine was measured using strain gage equipment. Changes in cylinder and feed screw configurations, screen type, cylinder speed and counter-pressure levels were examined to determine their impact on the quality and quantity of milled rice and the performance of the machine.

The results are summarized as follows:

1. The internal radial pressure in the whitening chamber varied with the surface condition of the grain being processed. During the first or second pass through the machine, pressure was relatively low, reached a maximum after two to three passes with combinations I and II, three to six with combination III and then began to fall.

2. The pitch of the feed screw and the size of the feed gate opening which determine the rate of entry of grain into the whitening chamber, appeared to be the most important factor affecting the degree of radial pressure, quality and quantity of milled rice and the efficiency of the machine.

Using a feed screw with a wide pitch (4.8cm), radial pressure was relatively high and head rice recovery ratio were quite low. In this case capacity and machine efficiency were much higher than obtained when using a feed screw with a narrow pitch (2.3cm).

Very significant responses in radial pressure, head rice recovery rates and machine capacity were observed with changes in cylinder speed and counter-pressure levels when using the wide pitch feed screw.

3. The characteristics of the screen which surrounds the whitening chamber had an important effect on whitening efficiency. The existence of small protuberances on the original screen resulted in significant increases in both machine capacity and efficiency but without a significant decrease in head rice recovery or development

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of excessive radial pressure. Further work is required to determine the effects of screen surface conditions and the shape of the cylinderical steel roller on the rate of bran removal, machine efficiency and recovery rates.

The size of the slotted perforations on the screen affects total milled rice recovery. The opening size on the original screen was fabricated to accommodate the round shape of Japonica rice varieties but was not suitable for the more slender Indica type. Milling Indica varieties with this screen resulted in a reduction in total milled rice recovery.

4. An increase in cylinder speed from 380 to 820 rpm produced a positive effect on head rice recovery for all machine combinations at every level of counter-pressure used in the tests. Head rice recovery was considerably lower at 380rpm using a wide screw pitch when compared to the results obtained at speeds from 600 to 820 r.p.m. The effects of cylinder speed on radial pressure, capacity and machine efficiency showed contrasting results, depending on the width of the feed screw pitch. With a narrow feed screw pitch (2.3cm), a direct proportional relationship was observed between cylinder speed and both radial pressure and machine efficiency. In contrast, using a 4.8 centimeter pitch feed roller produced a series of inverse relationships between the above variables.

Based on the results of this study it is recommended when milling Indica type long grain rice varieties that the cylinder speed of the original machine be increased from 500-600 rmp up to a minimum of 800 rpm to obtain a greater abrasive effect between the grain and the screen. The pitch of the feed screw should be also reduced to decrease the level of internal radial pressure and to obtain higher machine efficiency and increased quality of milled rice with increased cylinder speeds. Further study on the interaction between cylinder speed and feed screw pitch is recommended.

5. An increase in the counter pressure levelproduced a negative effect on the head rice recovery with an increase in radial pressure, capacity, and machine efficiency over all combinations and at every level of cylinder speed.

6. Head rice recovery rates were conditioned primarily by the pressure inside the whitening chamber. According to the empirical cha racteristics curve developed in this study, the relationships of head rice recovery (Y_h) and machine capacity (Y_c) to internal radial pressure (X_p) followed an inverse quadratic function and a linear function respectively:

$$\overset{\triangle}{Y}_h = \frac{1}{1.4383 - \overset{*}{0.2951} X_p + \overset{**}{0.1425} X_p^2}, \quad (R^2 = 0.98)$$

$$\overset{\triangle}{Y}_c = -305.83 + \overset{**}{374.37} X_p, \quad (R^2 = 0.88)$$

The correlation between capacity and power consumption per unit of brown rice (Y_e) expressed in the following exponential function:

$$\overset{\triangle}{Y}_e = 1.63 Y_c^{\overset{**}{-0.7786}} \quad (R^2 = 0.94)$$

These relationships indicate that when radial pressure increases above a certain range (1.6 to 2.0 kg/cm² based on the results of the experiment) head ricerecovery decreases in a quadratic relation with a inear increase in capacity but without any decrease in power consump tion per unit of brown rice. On the other hand, if radial pressure is below the range shown above, power consumption increases dramatically with a linear decrease in capacity but without significant increases in head rice recovery.

During the operation of a given whitening machine, the optimum radial pressure range or the correct capacity range should be selected by controlling the feed rate and/or counter-pressure keeping in mind the condition of the grain, particulary the hardness.

It was observed that the total number of passes is related to radial pessure level, feed rate and counter-pressure level. The higher theradial pressure the fewer number of pass required but with decreased head rice recovery. In particular, when using high feed rates, the total number of passes should be increased to more than three by reducing the counter-pressure level to avoid decreaseases in head rice recovery (less than 65 percent head rice recovery on the basis of brown rice) at every cylinder speed.

7. A rapid rise in grain temperature seemed to have a close relationship with the pressure generated inside the whitening chamber and, subsequently with head rice recovery rates. The higher the rate of increase, the lower were the resulting head rice recoveries.

1. Introduction

History contains numerous examples of rice mililng equipment which have been developed and utilized in rice producing countries to process rough rice (paddy) into edible white rice. In general, the milling systems adopted and unilized by the rice processing industry can be stratified into four categories: (1) the Engelberg milling sys tem, characterized by singlepass hulling and whitening, (2) the Europ ean milling system using the disc-type stone huller and vertical cone- type whitening, (3) the Japanese milling system which uses the rubber roll huller and horizontal friction and/or abrasive type whitening machine, and (4) the chemical milling system which employs a chemical solvent extraction and removal process.

Each system consists of several machines performing functions such as precleaning, hulling, separating, aspirating, elevating, whitening,grading and other operations.

With few exceptions, the whitening process is an indispensable part of the milling system. The role of the rice whitening machine is to remove the bran layer of the dehulled rice kernel without breaking the grain. The whitening process always takes place after the husk has been removed. It has been empirically observed that most broken grains are produced during the whitening process, particularly in Japanese milling system using rubber roll huller, although some breakage does occur during hulling.

A, Milling problems with Indica type rice varieties

The rice milling industry in Korea where the Japanese milling system is the most common currently faces several difficulties with the development and use of a new high yielding Indica type rice variety called "Tongil" (IR667). This variety has been available to Korean farmers since 1971 and is used on approximately 30 percent of the total rice area. Conventional friction type whitening machines which are widely used in Korea produce more broken grains from the new rice variety than are obtained with traditional rice varieties belonging to the Japonica type. The milling of the new rice variety with conventional whitening machines has led to an efficiency reduction in the quality and quantity of milled rice. "Tongil" yields 12 to 18 percent lower head rice and 1 to 2 percent lower total milled rice (brown rice basis)during the whitening process than traditional varieties.[39]

Most Asian countries where Indica type rice varieties are cultivated also produce both lower quality and quantity of milled rice. In some countries, modern Japanese milling machines have been introduced as pilot projects in areas growing Indica varieties to improve the quality of milled rice. Under these conditions, however, manufacturers of modern rice milling machines do not guarantee the head rice recovery and capacity of the machines to be the same as those described in their operational manuals.

Several factors should be considered in attempting to increase the quality ant quantity of milled rice. These include the chemical and physical characteristics of the rice kernel as well as the mechanical and operational features of the processing equipment. For example, Tongil has a higher amylose content, higher percentage of chalky kernels, longer grain size and more brittle grains than traditional rice varieties of the Japonica type.

As far as grain characteristics are concerned the traditional pressure type or Japanese modern abrasive whitening machines(and their operational manuals which are based on Japonica type rice varieties) will not be suitable for Indica type rice varieties without improving certain components of the machines or changing operational methods when using existing machines.

B. Objectives

Many studies have analyzed the effect of grain charatecristics on the resulting quality of milled rice using laboratory milling equipment. In contrast, very limited data is available showing the mechanical and operational effects on quality and quantity of milled rice. There are many mechanical and operational factors involved such as the speed of the mainshaft, screen type, cylinder type, feed rate, counter-pressure level on the outlet valve and others. Because of their effect on output efficiencies, it is particularly important to investigate for the pressure type whitening machine the effect of these factors on the internal forces to which grain is subjected while passing through the whitening chamber.

The general objectives is to obtain basic information which will improve the performance of existing rice whitening machines by promoting selective improvments in components of the machine or operational procedures.

The specific objectives of this study are to evaluate, through changes in screen types, cylineder and feed screw configurations, cylinder speeds and counter pressure levels (using a commercially available whitening machine and processing Indica type brown rice), the following: (1) changes in radial pressure developed inside the rice whitening chamber, (2) the effects of the above mentioned factors on head rice recovery, capacity of the machine, and power consumption, and (3) to develop an empirical characteristic curve involving the radial pressure and performance of the rice whitening machine.

2. Historical background of rice milling in Korea

A. Primitive milling

Before mechanical engine driven milling equipment were introduced into Korea in the 1930s, rice hulling and whitening were performed using primitive impact or frictional devices.

The simplest milling method utilizing impact force is hand pounding with a mortar and a pestle. Hand pounding is still used to a limited extent for milling rice in some Asian countries, notably Indonesia. An improvement in this technique was the installation of a lever-type wooden frame attached to the mortar to facilitate operation of the equipment with a treading action (locally called "Didil-Bangah"), and later, by the water wheel.28) During the same period, a vertical disc-type huller consisting of two pieces of log laid on top of each other (locally called "Tomae") was employed for hulling. This tool, which uses frictional force, was also operated by hand and was a precedessor of the modern rubber roll huller developed in Japan. 23) A friction type milling machine consisting of a large cylinderical stone with a disc-type stone base driven by animal power (locally called "Yun-ja-mae") was also used.

B. Mechanicalmilling

In 1923 Japan began mass production of kerosene engine. Concurrently, a horizontal friction-type rice whitening machine was developed by modifying the Engelberg rice huller imported from the U.S.23) This U.S. made rice huller was actually intended as a coffee huller.2) The kesosene engine and the friction type whitening machine were introduced into Korea in the 1930s during the Japanese colonial period. Following this event, serveral friction type whitening machines have been developed and unilized. Those whitening m achines being used in Korea can be divided into three types as follows:

Type 1: the horizontal friction type equipped with a cylinderical steel roller but without a jet air blower (pressure type)

Type 2: the horizontal friction type equipped with a cylinderical steel roller and a jet air blower (pressure and abrasive type)

Type 3: the horizontal abrasive type with a cylinderical emery stone roller (speed type)

Type 1 machines have become the most common used in Korea following the introduction of mechanical milling methods.

This type of machine is characterized by the development of high frictional force inside the rice whitening chamber as the grain is being processed. The bran layer is removed from the rice kernel by the rubbing action among grains by the rotating cylindrical roller inside the whitening chamber, which is composed of a cast-iron insert. The loose bran is removed by means of a slant sieve or a bran aspirator.

Type 2 and type 3 machines have been recently developed and are gradually replacing the type 1 machine. The working principle and structure of the type 2 machine is slightly different from type I. (Refer to section 1, chapter IV).

In the type 3 whitening machine, bran removal is mostly accomplished by the abrasive action between the grain and the emery surface of the cylinder. It is, therefore, believed that the pressure acting on the grain will be lower in type 3 than in types 1 and 2, resulting in a relatively higher head rice recovery. The type 3 whitening machine, however, produces rough surfaces on the final product. Consequently, a combination of types 2 and 3 machines in series tends to be employed in modern rice milling systems. More rescently, abrasive material has been adopted to the cylinder for a horizontal abrasive type whitening machine in Korea.

The recent status of milling facilities in Korea shows that there are 576 large scale milling plants (1972), processing about 20% of total production, and the rest is processed in about 20,000 small scale milling plants.

There are about 7,500 whitening machines employed by large scale milling plants. About 15% of these are type 2 machines, about 1.5% are type 3 and the rest belong to type 1. Most whitening machines employed by the small scale commercial mills are type 1, with a few exceptions.

3. Review of Literature

The quality and quantity of milled rice are affected by several factors which may be classified into two broad categories: (1) grain factors and (2) mechanical and operational factors. Grain factors which influence the quality of milled rice include production and post-production field operations such as harvesting, drying, storage and handling, and varietal characteristics such as length and thickness of grains, percent chalky kernells, hull thickness, protein content, etc. The mechanical and operational factors most directly related to the quality of milled rice will involve hulling, separating, whitening, the type of machine used, and the operational condition of the machine.

A. Grain factors

The moisture content at harvest of rough rice affects head rice recovery. Maximum head rice recovery is obtained at harvest moisture content of about 20 percent. [6, 18]

Faulkner and[6, 18] others found large difference in milling yields resulting from different methods of drying and pointed out the benefits of controlled drying over sun-drying. Sun-checking in the grain and subsequent breakage during milling can be reduced by using mechanical methods of drying.

The temperature of the drying air, the time-lag between drying and milling and the conditions of cooling after drying all affect the grain quality and subsequent milling yields. [12, 19, 5] Wasserman (1962) [5] reported that for carefully dried rice, the drier the rough rice, the higher the milling yields. This generally applied to both short and long grain rice milled in the McGill appraisal mill, and also short grain rice milled in the Engelberg commercial mill. Aroma, et al (1973)[14] concluded that a temperature difference of greater than 43°C between drying air and the rice kernels may result in serious cracking. Shin[9] mentioned that rice which is excessively dried (less than 14.0% w.b.) requires higher horsepower and longer milling time, resulting in greater power consumption than is required when paddy is moderately dried. Rice dried below 14% also exhibits no increase in head rice yields.

Juliano[16] (1973) concluded that brown rice becomes progressively more resistant to milling while held in storage, particularly at temperatures above 15°C. Total head rice yield also tended to increase. He also indicated that opaque portions in nonwaxy grains are caused by air spaces between the starch granules which result in softer grains that are more susceptible to breakage during milling. He further found that higher protein samples tend to be more resistant to milling and yield higher head rice recoveries.

The handling of paddy or brown rice prior to milling and the environmental conditions during milling will also affect the quality of milled rice and the performance of the machine. According to Wimberly,[13] the Central Food Technology Institute in India reported that parboiling gelatiniped the starch and thus solidifies the fractures in the rice grain. Therefore, head rice recovery is increased by 5-10% and total rice yield by 1%. Even very short intervals of steam treatment prior to drying caused an improvement in milling yields.[10] The maximum bending strength of individual grains increases with an increase in steaming time.

Wassermann, et al (1974)[22] reported that in a milling test using a commercial type Engelbgrg rice mill, water sprayed on the brown rice one minute before milling resulted in a 31% decrease in milling time, 41 percent decrease in energy use and 2.5 to 6.5 percent increase in total and head rice yields.

It was observed[1] (1953) that mill room temperature has a minor effect while relative humidity has a significant effect on head rice yields. The optimum relative humidity for milling rice is about 70 to 80 percent.

B. Mechanical and operational factors.

The quantity of broken grains produced sample hulling will be affected by the type of hulling machine and its operational performance. The maximum head grain recovery will be limited primarily by brown rice head grain recovery after hulling.

Covanich and De Padua (1973) reported that using three different types of laboratory shellers (A McGill equipped with rubber and steelrollers, a Satake equipped with two rubber rollers and and an Olmia with disc-type stones), hulled and head grain recoveries were affected by the clearance between the rollers or between the stone discs. Generally percent head grain recovery*) increases with increased clearance but the absolute amount of hulled grain is reduced.

Stipe, et al[10] (1971) provided test results designed whether the quality of milled rice is lowered when the paddy is shelled at high moisture levels. Head rice recovery*) decreased at high moisture levels. particularly for long grain varieties. Medium grain type, however, showed no significant difference at different moisture levels, although there is a slight indication that head yield may decrease when shelling is performed at the highest moisture levels (18%w.b.). Unhulled rice increased with increased moisture. On the other hand by adjusting the sheller clearance to obtain the same amount of hulled rice (about 98 percent) at various moisture levels, significant differences in head rice recovery were achieved after whitening.

A comparative performance trial[20] using three types***) of commercial hullers was performed (1974) at the Agricultural Engineering Department, IRRI. The results showed that the rubber roll huller produced comparatively higher hulled and head grain than others. The hulling efficiency of a centrifugal huller was relatively high, but many broken grains were produced.

Autrey[1] (1953) found that when using Zenith and Pexark varieties, head rice yields

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*) Percent head grain recovery=

$$\frac{\text{Weight of head grain}}{\text{Weight of hulled grain}}\times 100$$

**) The standard setting of the McGill laboratory sheller was used for shelling paddy samples. After shelling all samples were dried to 12% m.c. for whitening in McGill miller no. 3.

***) Three types of commercial shellers: rubber roll huller, under-runner disc sheller and centrifugal huller.

were closely related to the amount of bran removed. When 75 percent of the total bran is removed, about 20 percent total breakage results. Removal of the remaining 25 percent bran causes 80 percent of the total breakage.

The cylinder speed and counter pressure of the whitening machine does affect the performance of the machine. With the horizontal friction type whitening machine (type 1), an increase in the cylinder speed from 400 to 700 rpm under a fixed counter pressure resulted in an increase in both the power requirements and the hourly capacity of the machine.16) However, the capacity per horsepower-hour (efficiency of the machine) and the head rice recovery were reduced. Conversely, an increase in the counter pressure with a given cylinder speed resulted in an increase in hourly capacity as well as efficiency of the machine. The optimum cyclinder speed for the type 1 machine is 350 to 400 rpm, 600 to 800 rpm for type 2, and 800 to 900 rpm for type 3 respectinvly.

In type 1 whitening machine, partial removal removal of free bran early in the whitening sequence results in an increase in milling time. The presence of bran during the early stages of milling helps to develop pressure inside the whitening chamber and increases milling efficiency.4)

The quatity of brown rice in the feed hopper affects the horsepower requirement and the pressure inside the whitening chamber. The horsepower requirement also varies at different stages of milling due to changes in the condition of grain surface.4)

"Satake" Technical News Report reported that the pressure inside the whitening chamber of the type 3 whitening machine varies according to the grain flow rate, abrasive cylinder speed, grain size, counter pressure, etc. Both interal pressure and the discharge rate of milled grain can be adjusted by a resistance plate attached to the screen.

The same report also mentioned that if the temperature of the milled rice rises above a certain point, the rigidity of the grain will be lost and a higher degree of broken grains will be produced during the whitening process. On the other hand, if temperture is too low, the luster of the grains will diminish. During the whitening process, a temperature rise of 10 to 15° C above normal atmospheric temperature is considered most suitable.

For type 3 whitening machine uniform whitening of the grains is influnced by the density of grain inside the whitening chamber. If the density is high, individual grains will move along the periphery of the abrasive cylinder creating a flat surface which is not conductive to rolling and uniforn whitening. The result is non-uniform whitening and non-symmetrical grains. If, however, the density is low the grain roll is in a spherical pattern inside the whitening chamber resulting in uniform bran removal and a round, polished, white grain.23)

The sharpness of the abasive on the whitening cylinder has an important impact on the removal of the bran. A sharp edged abrasive surface produces a clean cutting effect with relatively low pressure inside the chamber.

Bhatia, et al(1968)7) concluded that internal air ventilation in the Engelberg huller showed a clear decrease in breakage as air flow rates increased.

Shin reported (1971)9) in a comparative performance test of whitening machines using Tongil rice variety, the type 3 machine produced higher head and milled rice recoveries than types 1 and 2.

A comparative performance test of different types of whitening machines conducted at the International Rice Research Institute(IRRI)[20] showed that machines equipped with abrasive emery stones (vertical abrsive cone type and horizontal cylinderical abrasive type) produced comparatively higher head rice recoveries than other friction type whitening machines. In contrast, the type 2 whitening machine gave the highest hourly capacity with the lowest head rice recovery.

Wimberly (1972) summarized the findings obtained from a series of evaluation tests for different milling systems conducted in India. The results showed that modern rice mills (rubber roll huller and horizontal abrasive and friction type whitening machine in series) produced the highest recovery in terms of head and milled rice for both raw and parboiled rice. The sheller mills (under-run disc sheller and vertical cone type whitener) ranked second in performance and the huller mills (Engelberg huller) third.

4. Equipment and Methodology

A. Equipment

1. Rice whitening machine.

In this study a slightly modified type 2 whitening machine made by a Korean company was used in the tests. A schematic diagram of the machine is shown in Fig. 1.

The adjustable feed gate valve(referred to hereafter as feed gate) controls the amount grain discharged from the intake hopper into the feed screw. The feed rate is governed primarily by the size of the feedgate opening and secondarily by the pitch and rotating speed of the feed screw. The feed screw a cylindrical cast-steel roller (referred to hereafter as the cylinder) having a long slotted opening

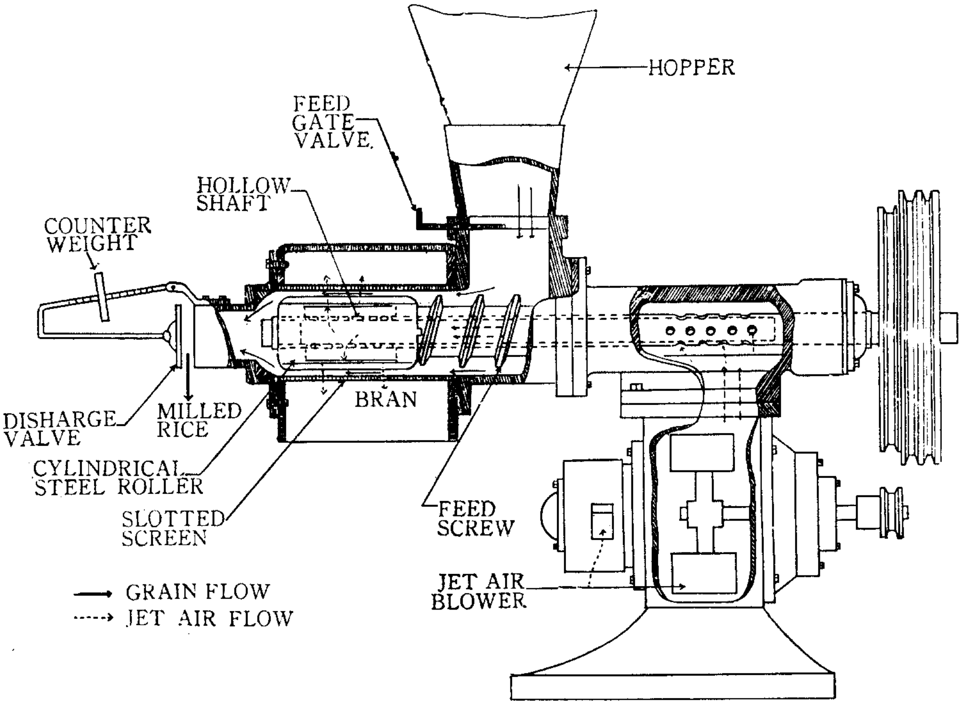


Fig. 1. Schematic drawing of the rice whitening machine

behind two fluted ridges are mounted on a horizontal, partly hollow, perforated shaft (referred to hereafter as the shaft). A hexagonal whitening chamber is formed by two half-hexagonal screens (referred to hereafter as the screen) with slotted perforations and convex protuberance (refer to Fig. 4). During operation, counter-pressue inside the whitening chamber can be controlled by sliding a balance weight outward or inward from the discharge valve.

Brown rice fed into the intake hopper moves through the feed gate and the feed screw into the space between the cylinder and the screen. Bran removal is accomplished by friction created by surface contact among grains andthe abrasive action between the screen and the grain. The degree of pressure and friction exerted on the grain results from the interaction of the feed screw, the counter-pressure on the discharge valve and the radial pressure caused by the rotation of the cylinder. A strong airstream from the blower enters the hollow shaft and openings of the rotating cylinder where it passes through the rice grain inside the whitening chamber. The airstream forces loose bran inside the chamber through the openings of the screen, and also decreases the temperature of the grain being processed.

In order investigate the effects of alternative cylinder and screen types, various cylinder speeds and counter-pressure levels on the internal radial pressure in the whitening chamber and the performance of the machine, several modifications specified in Table 1 and Fig. 2 were introduced.

To decrease the feed rate and the axial force acting on the grain, a feed screw with a relatively narrow pitch was fabricated(cylinder B). Screen B, which has no protuberances on he screen surface, was used to determine the effect of the screen shape on this performance of machine. A low cylinder speed used with the wheel whitening machine was

Table 1. Specifications of original and modified components of type 2 whitening machine.

items	type or symbol	size or levels	remarks
cylinder	A (original)	L×d (cm) 16.7×10.1	Assembled with the feed screw having wide pitch (pitch×depth=4.8×1.5cm). Total length of cylinder and feed screw=32.2cm.
	B (new)	L×d* 22.2×10.1	Assembled with the feed screw having narrow pitch (pitch×depth=2.3×1.5cm). Total length of cylinder and feed screw=32.2cm.
screen	A (original)	L×D* 21.8×11.1	Having concave protuberances and relativaly large slotted perforations (1.2×0.12cm)
	B (new)	21.8×11.1	Having smooth surface, two steel blades with "L" type edge, and small slotted perforations (1.15×0.07cm).
cylinder speed	S_1 S_1 S_3	380 rpm 600 820	The original recommended rpm range was 500 to 600 rpm.
counter pressure	P_1 P_2 P_3	14.8g/cm² 17.6 20.4	The counter pressure per cm² of outlet is controlled by moving the weight on the steel beam. Outlet area=95.0 cm²

clearance	C	0.5cm	The same clearance was used for three combinations.
motor	three-phase	10 Hp	Motor efficiency (ef)×power factor (Pf)=0.717
jet air blower	centrifugal fan	3300 rpm	Almost constant rpm was used for three noch combinations.

* Refer to the section A-A of Fig. 4.

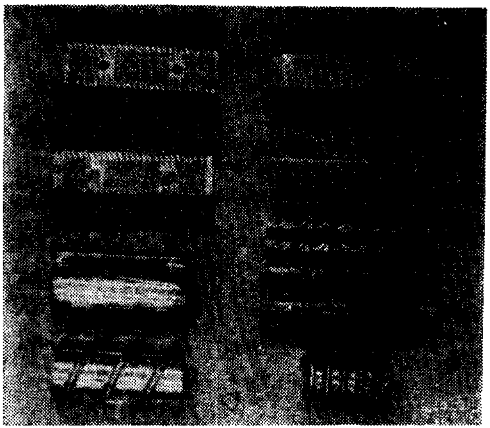


Fig. 2. Original (A) and modified (B) screen, roller and feed screw.

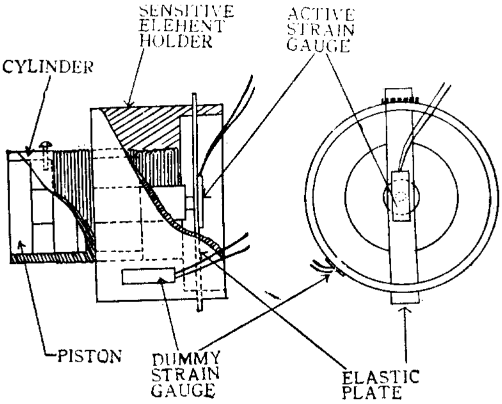
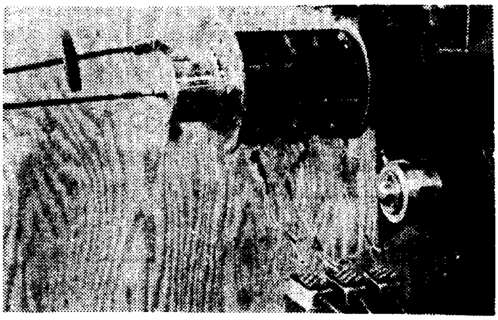


Fig. 3. Schematic drawing of the compressive load cell.



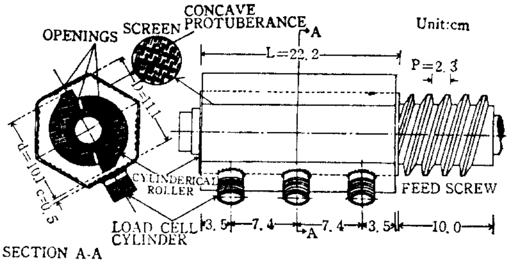
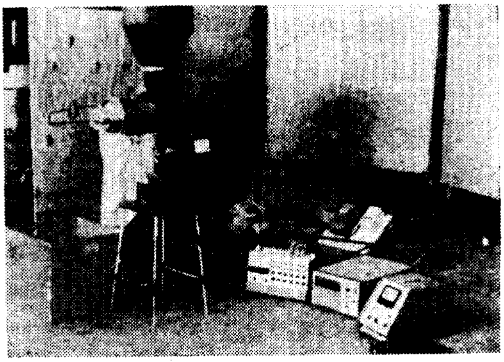
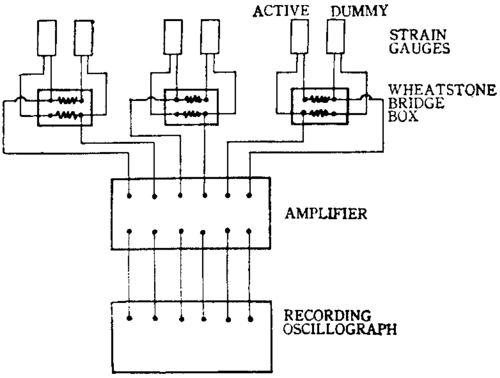


Fig. 4. Placement of load cells on the screen (Cylinder B and screen A).



A. Whole view



B. Schematic wiring diagram

Fig. 5. The composite view of experimental apparatus (A) and wiring diagram of meas urement equipment (B).

selected to ascertain the possibility of using the type 2 whitening machine with existing milling systems without changing cylinder speed.

2) Measurement of radial pressure.

To measure the internal radial pressure developed in the whitening chamber, a "Kyowa" dynamic strain gauge instrument consisting of a Wheatstone bridge box, DPM 6E dynamic strain amplifier, and RMV 33R direct recording oscillograph was used in conjunction with three compressive load cells which were fabricated (Fig. 3) and installed at three equally spaced intervals on the screen (inlet, center and outlet) (Fig. 4). .

The load cell consists of a cylinder, a piston moving inside the cylinder, a sensitive element consisting of an elastic steel plate on which an active strain gauge is attached, and a sensitive element holder on which a dummy strain gauge is installed. When the piston is sujected to a radial compressive force, a bending stress will take place in the sensitive element, resulting in tension in the strain gauge filament which is installed on the rear of the sensitive element. The strain is magnified by an amplifier and recorded on a strip chart by the oscillograph. The experimental apparatus and the schematic wiring diagram of this system is show in Fig. 5.

The caliberation curve which shows the relationship between the compressive force (X) and the magnified strain (Y) for each load cell was produced by adding the known weight and reading the scale of the strip chart recording the magnified strain. Three caliberation curves representing each load cell were shown as follows:

$Y_1=0.0797+3.6794X$ (Installed at the inlet) $(R^2=0.998)$

$Y_2=1.0074+3.1549X$ (Installed att the center) $(R^2=0.997)$

$Y_3=0.3489+3.5737X$ (Installed at the outlet) $(R^2=0.998)$

where, $0 \leqq X \leqq 14.0$kg

B. Methodology

1) Experimental design

By using both the original (A) and new (B) cylinders, feed screws, and screens, three alternative machine combinations were assembled for the experiment.

Combination I (CI) : cylinder A and screen A

Combination II (CII) : cylinder B and screen A

Combination III(CIII) : cylinder B and screen B

A split-split plot design was used with a latin square arrangement for the main plot. Three machine combinations were assigned to the main plot, three levels of cylinder speed to the sub-plot and three levels of counterpressure to the sub-subplot.

Three replications were used in each treatment. The effect of the cylinder and feed screw was examined by comparing CI and while the effect of screen type was obtained by comparing CII and CIII.

2) Preparation of samples

Paddy samples of the same variety planted

Table 2. Information on the brown rice sample.

item	sample Group		remarks
	No. 1 and 2	No. 3	
varietal line	IR2071-88-3		
grain size:length	6.27		average value
(mm) width	2.16		of 10 grains

thickness	1.68		
L/T	3.73		
bulk density(kg/litter)	794.2		
moisture content (%, w.b.)	12.0	11.9	
head grain (%)	93.9	94.7	
sound grain	85.0	80.1	
greenish grain	2.8	1.8	
stained grain	2.5	1.7	
cracked grain	3.6	11.0	
broken grain (%)	2.1	3.5	
unhulled paddy, (%)	3.3	1.5	
foreign matters, (%)	0.5	0.1	
cracking hardness of hulled rice (kg/grain)			
sound grain		5.15 (σ=0.72)	mean values of 10 to 16 grains
greenish grain		4.52 (σ=0.63)	
chalky grain		2.65 (σ=0.36)	
lab. whitening test			
total milled rice recovery (% brown rice basis by weight)	92.2	92.4	
head rice recovery	80.6	74.9	
broken grains	11.6	17.5	
percentage of hull of paddy (paddy basis)	23.1		

on the same field and harvested and dried at the same period using the same methods were obtained from the IRRI farm office. About 2.0 tons of paddy were divided into three lots, each was thoroughly mixed and hulled using a rubber roll huller. In order to secure maximum hulled rice from the paddy material, two passes were made through the huller. Table 2 shows information on the brown rice sample by group.

The sample size for each test run (15 kg) counter-pressure levels, and the optimum opening of the feed gate were determined in a series of preliminary tests based on the operational manual for the machine. The opening of the feed gate was held constant for all tests. The degree of whiteness of the final product was determined by using 8 percent bran removal by weight (brown rice basis) as the standard and was measured using a "Kett" whiteness meter (Fig. 6). This procedure produced an almost uniform whiteness in the final products from each test run. The whiteness index of the final product ranged from 33.0 to 35.0 on the whitensess meter.

During the test runs, about 500 gram samples were taken from the output. Information describing the weight of the milled rice, temperature of milled rice, the electric current of the motor, milling time and the weight of the byproducts were recorded.

The recording charts indicating the radial pressure inside the whitening chamber were produced by activating the recording oscillograph during each trial run.

After each test, a byproduct sample of about 200 grams was taken to analyze the broken grains contained in the byproducts.

3) Laboratory analysis of the samples.

Paddy and brown rice sample: In order to measure the physical characteristics of the paddy and the brown rice samples described in Table 2 about three kilograms of paddy and five kilograms of brown rice were taken from each sample group using a probe sampler.

The moisture content of the brown rice samples was measured using a 105°C air oven drying method with five 30 gram samples from each sample group.

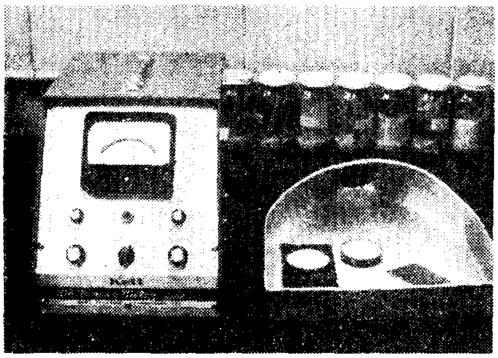


Fig. 6. "Kett" whiteness meter.

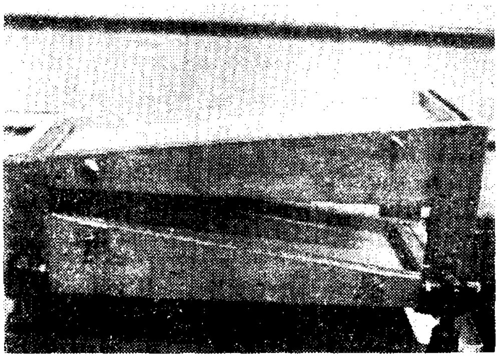


Fig. 7. Head grain separator

The percent hull (by weight) was determined using a laboratory rubber roll huller.

Three 100 grams of brown rice from each group were used for quality analysis of each brown rice sample. Whole grain sand unhulled paddy were separated from the broken grain using a hand separator or by hand segregation. The whole grains were magnified to separate the cracked grains, stained grains, and greenish grains from sound grains.

Laboratory whitening tests were conducted using ten brown rice samples of 100 grams from each sample group milled group milled n McGill No. III laboratory whitener. This test was designed to determine the whiteness index of the final product on the basis of 8% bran removal by weight and to obtain information on the maximum head rice recovery from the brown rice samples.

Grain hardness was measured with a grain hardness tester made by Kiya Seisakusho, Ltd.

Milled rice and byproducts: To determine the amount of head rice, broken grains(large brokens+small brokens), impurities and unhulled grains, three 100 gram subsamples were separated from the 500 gram samples and analyzed by means of a mechanical separator(Fig. 7). Fourfifth whole grains were considered to be head rice. The mean value of the three sub-samples were used as an index of the quality of the final products for each test run.

From the byproduct samples two 100 gram sub-samples were weighed and analyzed for the percentage of broken grains, including "brewers" contained in the byproducts by means of a Tayler sieve and blower.

5. Results and Discussion

A. Distribution of radial pressure inside the whiteuing chamber.

The radial pressure developed inside the whitening chamber was obtained from the radial pressure recording chart shown in Fig. 8.

To compare the radial pressure between each pass, average radial pressure (per cm² of piston area of the load cell) was computed from the three values measured at three locations on the screenduring each pass. For combination I, equipped with a relatively shorter cylinder only two radial pressure values were obtained at the linlet and outlet. These two values were used to compute the average radial pressure.

Total average radial pressure for each test run was calculated from the average radial pressure values representing each pass.

In gneral, the radial pressure in combinations I and II was higher at the inlet side than the outlet, but in combination III this was reversed. These results might be due to the different surface of the screen.

The radial pressure also varied with the number of passes. Pressure rose in the first passes through the machine, reached a maximum, and then fell as whitening proceeded (Fig. 9). The peak pressure appeared on the second or third cycle with combinations I and II, and the third to sixth cycle with combination III. The total number of passes required to achieve the predetermined degree of whiteness was two to four times with combinations I and II, and six to seventeen times with combination III. The relation of variations in the radial pressure with the number of passes can be attributed to changes in surface texture of the grain as it is processed. During the early stages of processing the bran layer is scratched by the rubbing action among grains and between the grain and the surface of the screen. As the bran layer is removed, the surface of the grain becomes smooth and shiny, and the frictional force among grains will subsequently be reduced. This may indicate that the condition of the grain surface influences the pressure inside the whitening chamber.

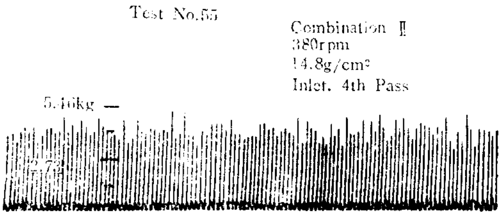


Fig. 8. Pressure recording chart.

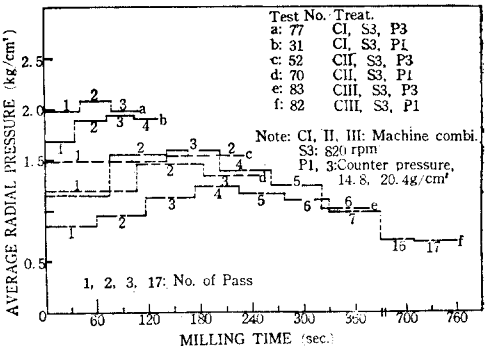


Fig. 9. Changes in radial pressure along the the number of pass and milling time by machine combination.

B. The effect of cylinder speed, counter pressure, screen type and cy-linder modification including feed screw (hereafter referred to as four factors) **on radial pressure in the whitening chamber.**

The results of a statistical analysis using the total average pressures representineg each test run are shown in Appendix I-1 and Tables 3 and 4.

Fig. 10 shows the surface response of the radial pressure to changes in cylinder speed and counter-pressure levels in the different machine combinations. The average radial pressure for combination I ranged from 1.90 to 3.24kg/cm², 1.10 to 1.53kg/cm² for combination II, and 0.98 to 1.44kg/cm² for combination III, respectively.

The result of comparisons among machine combinations shows that the radial pressure of combination I equipped with a relatively wide pitch feed screw (4.8cm) was considerably higher than those of combinations II and III equipped with narrow pitch feed screw (2.3 cm) at every level of the cylinder speed and counter-pressure. The differences between combination II and III were also considered significant at almost every level of counter-pressure and cylinder speed (Tables 3 and 4).

This result indicates that the wide screw pitch produces a high feed rate and increases the amount of grain per unit time passing through the annular space between the screen and cylinder, which leads to high radial pressures.

Screen A, having hemispherically shaped protuberances on the screen surface, produced higher radial pressures than screen B, which has a smooth surface and two steel blades with an "L" type edge. The former produced higher frictional force on the grain than the latter.

For all machine combinations an increase in counter pressure resulted in an increase in the radial pressure at every level of cylinders speed. There was also an interaction between the counter pressure level and the machine combination (Fig. 11).

In combination I the radial pressure response to changes in the counter-pressure level was much more sensitive than those observed in other combinations equipped with the narrow pitch feed screw. The differences in radial pressure between different levels of counter pressure were highly significant. In contrast, combination II did not exhibit statistically significant differences between different counter-pressure levels at the 5 percent level, while combination III indicated appreciable differences (Table 3).

It is apparent that the effect of counter pressure on radial pressure is different for alternative feed rate levels as well as for different screen configurations.

In examining the effect of cylinder speed on radial pressure (Table 4 and Fig. 12) combination I showed decreased radial pressure with an increase in cylinder speed. The difference between the two means at 380 rpm and 600 rpm was highly significant at the 1 percent level, while the difference between 600 and 820 rpm was not. In combinations II and III, however, the radial pressure increased slightly with an increase in cylinder speed.

Table 3. Differences in means for radial pressure between two machine combinations (C) at a constant counter-pressure (P) and between two counter-pressure levels within machine combinations·

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
P:$_1$	2.06	** (0.76)	1.30	** (0.25)	1.05	1.47
Difference P_1 vs P_2	** (0.21)		ns (0.04)		** (0.14)	
P_2	2.27	** (0.93)	1.34	(0.15)	1.19	1.60
Difference P_2 vs P_3	** (0.36)		ns (0.05)		** (0.16)	
P_3	2.63	** (1.24)	1.39	ns (0.04)	1.35	1.79
Differencens P_1 vs P_3	** (0.57)		ns (0.09)		** (0.30)	
Mean	2.32		1.34		1.19	1.62

LSD for the difference between two counter-pressure levels within combination:

5% : 0.10
1% : 0.13

LSD for the difference between two machine combinations at the same or different levels of counter-pressure-

5% : 0.16
1% : 0.23

Note: $P_1=14.8$, $P_2=17.6$, $P_3=20.4 g/cm^2$
CI = Cylinder A + Screen A
CII = Cylinder B + Screen A
CIII = Cylinder B + Screen B

Table 4. Differences in means for radial pressure between two machine combinations (C) at a constant cylinder speed and between two cylinder speed levels (S) within machine combinations.

	CI	Difference CI vs CII	CII	Differenc CII vs CI	CIII	Mean
S_1	2.84	** (1.71)	1.13	ns (0.02)	1.11	1.47
Difference S_1 vs S_2	** (-0.73)		** (0.30)		ns (0.12)	
S_2	2.11	** (0.68)	1.43	* (0.20)	1.23	1.60
Difference S_2 vs S_3	ns (-0.10)		ns (0.04)		ns (0.02)	
S_3	2.01	** (0.54)	1.47	* (0.22)	1.25	1.79
Difference S_1 vs S_3	** (-0.82)		** (0.34)		ns (0.14)	
Mean	2.32		1.34		1.19	1.62

LSD for the difference between two cylinder speed levels within combination:

5% : 0.19
1% : 0.27

LSD for the difference between two machine combinations at the same or dfferent levels of cylinder speed:

5% : 0.16
1% : 0.23

Note: $S_1=380$, $S_2=600$, $S_3=820$rpm
CI = Cylinder A + Screen A
CII = Cylinder B + Screen A
CIII = Cylinder B + Screen B

$$YCI=4.4150-\overset{**}{0.0057}X_1-\overset{**}{0.1121}X_2+0.6\overset{**}{\times}10^{-}X_1^2$$
$$+\overset{n.s.}{0.096}\cdot X^2{}_2-\overset{**}{0.199}\times10^{-3}X_1X_2 \quad (R^2=0.99)$$
$$YCII=0.0727+\overset{**}{0.0037}X_1-\overset{**}{0.0173}X_2-\overset{**}{0.217}\times10^{-5}$$
$$X^2{}_1+\overset{n.s.}{0.0013}X^2{}_2-\overset{n.s.}{0.16}\times10^{-4}X_1X_2 \quad (R=0.99)$$
$$YCIII=0.0381-\overset{n.s.}{0.0012}X_1+\overset{*}{0.1126}X_2+\overset{n.s.}{0.27}\times1$$
$$0^{-6}X_1{}^{22}-\overset{n.s.}{0.0028}X^2{}_2+\overset{n.s.}{0.69}\times10^{-4}X_1X_2(R^2=0.99)$$

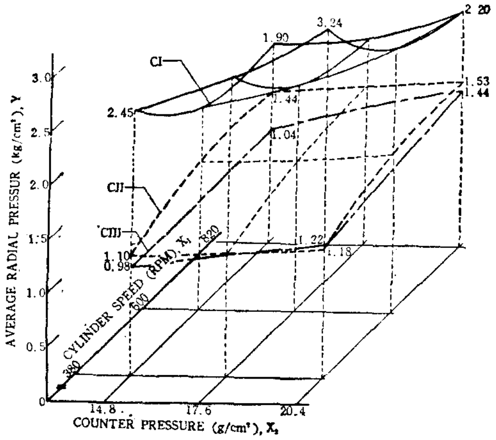


Fig. 10. Estimated surface response of radial pressure to changes in cyinder speed and counter-pressure levels by machine combination.

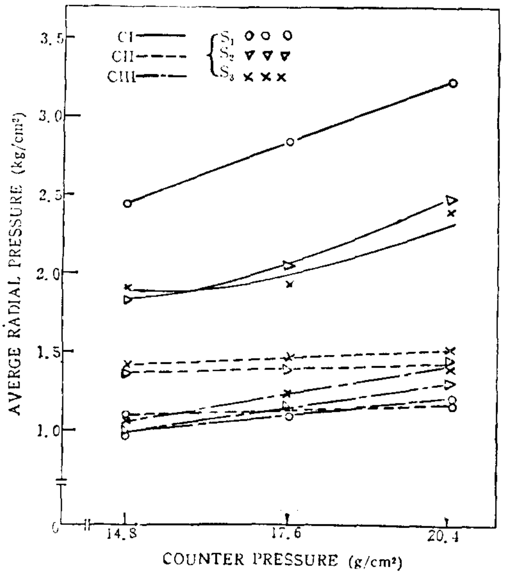


Fig. 11. **Effect of counter-pressure on internal radial pressure by mcahine combination (C) and cylinder speed (S).**

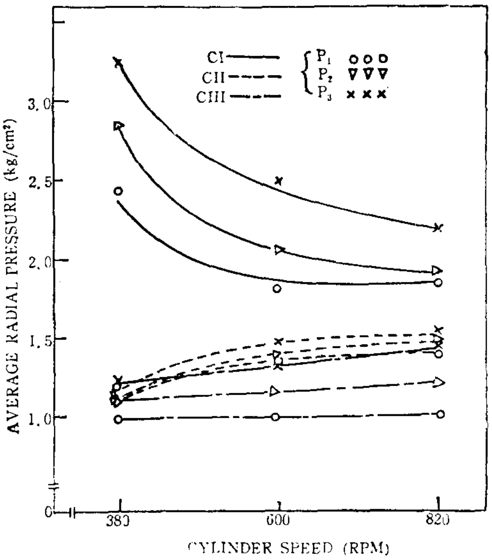


Fig. 12. **Effect of cyinder speed on internal radial pressure by machine combination (C) and counter-pressure level (P).**

The interaction between cylinder speed and the machine combination cannot be explained fully with this limited data, but it is hypothesized that when the pressure inside the whitening chamber is above a certain level, the feed rate cannot be increased through an increase in the cylinder speed because of the slippage that occurs between the grain and feed screw. It is also likely that the grain density inside the whitening chamber is lower at higher cylinder speeds and the radial pressure and capacity of the machine (refer to section 4 of this chapter) will decrease accordingly.

☆ In summary, it appears that the important mechanical factors affecting the degree of radial pressure inside the whitening chamber are (1) feed screw pitch controlling the feed rate and (2) the shape of the screen surface. A direct proportional relationship exists between the counter-pressure and the radial pressure at every level of cylinder speed and feed rate. The effect of cylinder speed displayed a variety of results depending on the width of the feed screw pitch with a direct proportional relationship using a relatively narrow pitch feed screw and an inverse relationship when using a wide pitch feed screw.

C. Effect of four factors on percent milled and head rice recovery.

The percent head and milled rice recovery for each test run was computed using the following formulae:

Percent head rice recovery=

$$\frac{\text{Total weight of head rice recovered}}{\text{Total weight of brown rice sample used}} \times 100$$

Percent milled rice recovery=

$$\frac{\text{Total weight of milled rice recovered}}{\text{Total weight of brown rice sample used}} \times 100$$

1) **Head rice recovery.** A statistical analysis was carried out using the percent head rice recovery from each test run as the dependent variable (Appendix I-2).

Three multiple regression functions showing response of percent head rice recovery to changes in cylinder speed and counter-pressure levels were obtained from the three machine combinatons (Fig. 13).

Combination I, which had a relatively higher radial pressure than others, showed measurably lower head rice recovery than combination II at every level of cylinder speed or counter pressure, in particular, at low rpm levels. It was, however. noted that the differences between combinations II and III, which had relatively lower levels of radial pressure, were insignificant at the same or different levels of cylinder speed or counter-pressure.

Counter-pressure had a positive effect on the development of the radial pressure but gave a negative effect on head rice recovery at all levels of the cylinder speed (Fig. 14). An increase in the cylinder speed from 380 to 820 rpm displayed a positive effect on head rice yields at all levels of counter-pressure and for all machine combinations. (Fig.15).

In machine combination I, highly significant differences in the head rice recovery were observed between different cylinder speed settings and also between different counter-pressure levels. In combinations II and III, however, the differences were not statistically significant (Tables 5 and 6).

From these results, it appears that the percent head rice recovery is partially due to the pressure level developed inside the whitening chamber. If the pressure is below a certain level the effects of screen type, cylinder speed and counter-pressure on head rice recovery are relatively minor. The pitch of the feed screw, which was the most important factor governing the level of radial pressure

Table. 5. Differences in means for percent head rice recovery between two machine combinations (C) at a constant counter-pressure and between two counter-pressure levels (P) within machine combinations.

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
P_1	75.88	ns (1.69)	77.57	ns (0.56)	78.13	74.73
Difference P_1 vs P_2	** (-9.30)		ns (-0.85)		ns (-0.53)	
P_2	66.58	* (10.14)	76.72	ns (0.88)	77.60	73.63
Difference P_2 vs P_3	* (-2.02)		ns (0.19)		ns (-1.44)	
P_3	64.56	** (12.35)	76.91	ns (-0.75)	76.16	72.53
Difference P_1 vs P_3	** (-11.32)		ns (-0.66)		* (-1.97)	
Mean	66.53		77.06		77.30	73.63

LSD for the difference between two counter-pressure levels within combination:

5% : 1.65
1% : 2.22

LSD for the difference between two machine combinations at the same or different levels of the counter precessure:

5% : 5.59
1% : 10.27

Note: $P_1=14.8$, $P_2=17.6$, $P_3=20.4 g/cm^2$
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

Table 6. Differences in means for percent head rice recovery between two machine coimbinatons (C) at constant cylinder speed and between two cylinder speed levels (S) within machine combinations.

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
S_1	55.23	** (21.08)	76.31	n.s. (-1.08)	75.43	68.96
Difference S_1 vs S_2	** (14.47)		ns (0.57)		n.s. (2.21)	
S_2	69.70	* (7.18)	76.88	n.s. (0.76)	77.64	74.74
Difference S_2 vs S_3	** (4.96)		ns (1.12)		n.s. (1.23)	
S_3	74.66	n.s. (3.34)	78.00	n.s. (0.92)	78.92	77.19
Difference S_1 vs S_3	** (19.43)		ns (1.69)		* (3.49)	
Mean	66.53		77.06		77.30	73.63

LSD for the difference between two cylinder speed levels within combination:

5% : 2.69
1% : 3.77

LSD for the difference between two machine combinations at the same or different levels of cylinder speed:

5% : 5.32
1% : 8.82

Note: $S_1=380$, $S_2=600$, S_3 820 rpm
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

$$YCI=26.48+0.1\overset{**}{3}38X_1-\overset{**}{0}.5724X_2-0.\overset{**}{0}001^2{}_1-\overset{n.s.}{0.0253}X^2{}_2+\overset{n.s.}{0.013}X_1X_2\ (R^2=0.99)$$

$$YCII=88.60+0.\overset{*}{0}058X_1-\overset{n.s.}{1.5196}X_2-\overset{n.s.}{0.9}\times 10^{-6}X^2{}_1+\overset{n.s.}{0.0374}X^2{}_2-\overset{n.s.}{0.6}\times 10^{-5}X_1X_2\ (R^2=0.99)$$

$$YCIII=79.22+0.00\overset{*}{8}3X_2-0.19\overset{*}{4}X_2-\overset{n.s.}{0.3}\times 10^{-5}X_1{}^2-\overset{n.s.}{0.098}X^2{}_2+\overset{n.s.}{0.92}\times 10^{-4}X_2X_2\ (R^2=0.99)$$

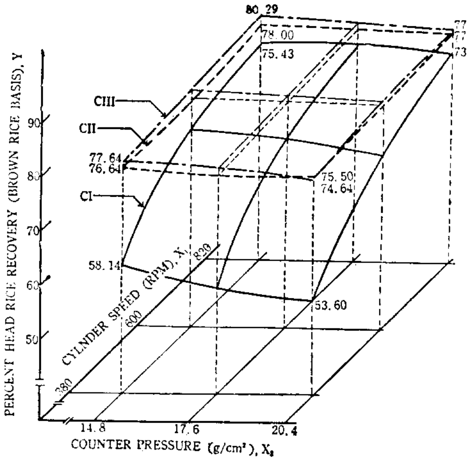


Fig. 13. Estimated surface response of head rice recovery to changes in cyinder speed and counter-pressure levels by machine combina-tion.

developed in the machine, is the main factor affecting head rice recovery. In considering the effects of counter-pressure and cylinder speed on head rice recovery and their relationship with radial pressure, it is the former which increases the directional force acting on the grain and also the density of the grain inside the chamber. Increased counter-pressure always produced lower head rice yields. Conversely, an increase in cylinder speed, even though accompanied by a slight increase in radial pressure (as long as the pressure remains at a relatively low level) produces higher head rice yields. This may result from the increase in abrasive action between the screen surface and the grain.

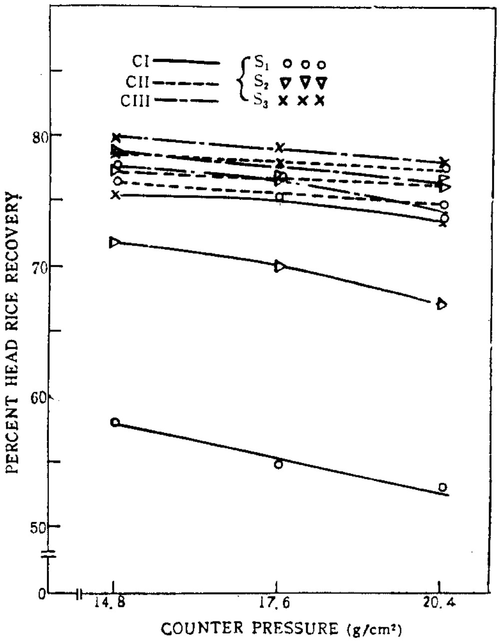


Fig. 14 Effect of counter-pressureon head rice recovery by machine combination (C) and cyinnder speed (S).

2. **Total milled rice recovery.** Total milled rice recovery showed no statistically significant differences among machine combinations at the same levels of counter-pressure or cylinder speed. Only two cases at the lowest cylinder speed and the highest counter-pressure level in combination I gave significant differences (Appendix I-3, Tables 7 and 8).

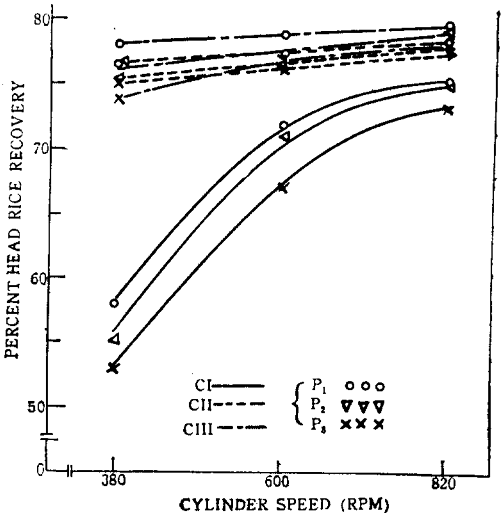


Fig. 15 Effect of cylinder speed on head rice recovery by machine combination (C) and counter-pressure (P).

This combination also produced the lowest head rice recoveries. It was, however, noted that the higher the head rice recovery, the higher is total milled rice recovery (Fig. 16)

A comparison of total milled rice recovery between combinations II and III, which had nearly identical head rice recoveries, indicated about a one percent difference with a slight advantage for combination III at every level of cylinder speed. This could be ascribed to the larger screen openings in the former than in the latter (refer to section

Table 7. Differences in means for percent total milled rice recovery between two machine combinations (C) at a constant counter-pressure and between counter-dressure and between counter-pressure levels (P) within machine combinations.

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
P_1	89.63	(0.54)	9 0.17	(1.01)	91.18	90.33
Difference P_1 vs P_2	(0.33)		(0.15)		(-0.25)	
P_2	89.86	(0.36)	90.32	(0.61)	90.93	90.40
Difference P_2 vs P_3	* (-0.82)		(-0.08)		(0.32)	
P_3	89.14	(1.10)	90.24	(1.01)	91.25	90.21
Difference P_1 vs P_3	(-0.49)		(0.07)		(0.07)	
Mean	89.58		90.24		91.12	90.31

LSD for differences between two counter-pressure levels within combination:

5% : 0.65
1% : 0.87

LSD for differences between two combinations at the same or different levels of counter pressure:

5% : 2.01
1% : 3.70

Note: $P_1=14.8$, $P_2=17.6$, $P_3=20.4 g/cm^2$
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

Table 8. Differences in means for percent total milled rice recovery between two machine combinations at a constant cylinder speed and between cylinder speed levels within machine combinations.

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
S_1	88.42	* (2.10)	90.52	(0.48)	90.90	89.95
Difference S_1 vs S_2	* (1.34)		(-0.59)		(0.16)	
S_2	89.76	(0.17)	89.93	(1.93)	91.06	90.25
Difference S_2 vs S_3	(0.81)		(0.33)		(0.35)	
S_3	90.57	(-0.31)	90.26	(1.15)	91.41	90.75
Difference S_1 vs S_3	** (2.15)		(-0.26)		(0.51)	
Mean	89.58		90.24		90.12	90.31

LSD for differences between two cylinder speed levels within combination:

5% : 1.10
1% : 1.54

LSD for differences between two combinations at the same or different levels of cylinder speed:

5% : 1.97
1% : 3.63

Note: $S_1=380$ rpm, $S_2=600$ rpm, $S_3=820$ rpm
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

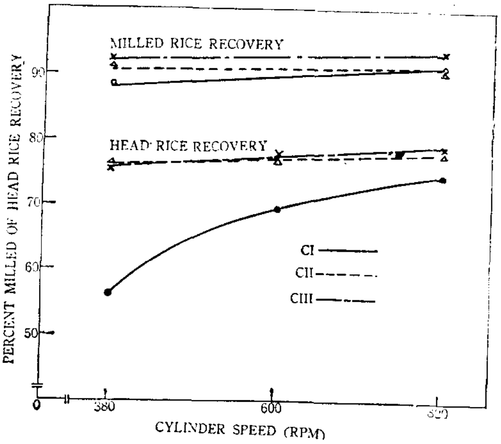


Fig. 16. Percent total milled and head rice recoveries.

6 of this chapter).

D. Effect of four factors on machine capacity, electric power consumption and machine efficiency.

1. Machine capacity. Machine capacity for each test run was based on the milling time measured during the test. These data were then subjected to statistical analysis (Appendix I-4).

For all machine combinations an increase in counter-pressure was related to an increase in capacity with the exception of one case at 820 rpm using combination II (Fig. 17).

The capacity of combination I was measurably affected by changes in counter-pressure levels. In combinations II and III, however, the effects of counter-pressure on differences in capacity was not statistically significant at the 5 percent level (Table 9).

Examining the effect of cylinder speed on machine capacity, we found that combination I showed an inverse relationship, while combinations II and III indicated a direct proportional relationship (Table 10 & Fig. 18). Based on these findings, it is hypothesized that the effect of cylinder speed will differ depending on the pressure level developed inside the whitening chamber.

A comparison of capacities among combinations indicated that at every level of the counter-pressure or cylinder speed the capacity of combination I was much greater than combination II. Significant differences at the 5% level were also found between combinations II and III.

In summary, it was observed that the capacity of the milling machine was principally affected by feed screw pitch, screen type, cylinder speed and the interaction between the feed screw pitch and cylinder speed.

In particular, the presence of the semi-ball shpaed protuberances on the screen surface seemed to have a considerable effect on the capacity of the machine without prodccing any appreciable decrease in head rice recovery. This may be due to an increase in the abrasive effect between the grain and the screen surface.

Further study of shape, size and arrangement of the protuberance will be important

Table 9. Differences in means for hourly capacity between two machine combinations (C) at a constant-pressure (P) and between two counter-pressure levels within machine combinations.

unit:kg/hr

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
P_1	530.4	** (337.7)	192.7	* (133.1)	59.6	251.9
Difference P_1 vs P_3	** (126.8)		ns (4.2)		ns (19.3)	
P_2	630.2	** (433.3)	196.9	* (118.0)	78.9	301.9
Difference P_2 vs P_3	** (103.2)		ns (-3.0)		ns (26.5)	
P_3	733.4	** (539.5)	193.9	* (88.5)	105.4	344.3
Difference P_1 vs P_3	** (203.0)		ns (1.2)		ns (45.8)	
Mean	622.4		194.4		81.3	

LSD for difference between two counter-pressure levels within combination

5% : 51.1
1% : 68.6

LSD for the difference between swo machine Combinations at the same or different levels Cylinder speed:

5% : 84.0
1% : 131.8

Note: P_1=14.8, P_2=17.6, P_3=20.4g/cm$_2$
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

Table 10. Differences is means for hourly capacity between two machine combination combinations (C) at a constant cylinder speed and between cylinderspeed levels (S) with ine combinations.

unit: kg/hr

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CII	Mean
S_1	685.3	** (544.0)	141.3	* (95.3)	46.0	290.9
Difference S_1 vs S_2	ns (-6.4)		** (62.1)		* (39.7)	
S_2	678.9	** (475.5)	203.4	* (117.7)	85.7	322.7
Difference S_2 vs S_3	** (-176.0)		* (34.9)		ns (26.5)	
S_3	502.9	** (264.6)	238.3	* (126.1)	112.2	284.5
Difference S_1 vs S_3	** (-183.4)		** (97.0)		** (66.2)	
Mean	622.4		194.4		81.3	299.3

LSD for the difference between two cylinder speed levels whithin combination:

5% : 30.5
1% : 42.8

LSD for the difference between two machine combinations at the same or different levels of the cylinder speed:

5% : 88.8
1% : 163.1

Note: $S_1=380$, $S_2=600$, $S_3=820$ rpm
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

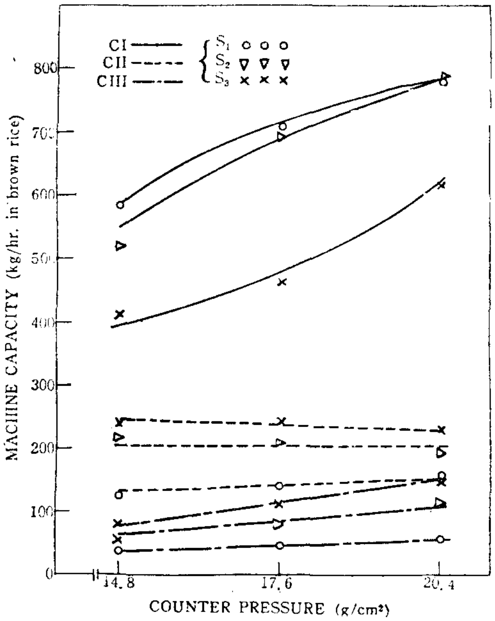


Fig. 17. Effect of counter-pressure on machine capacityby machine combination (C) and cylinder speed (S).

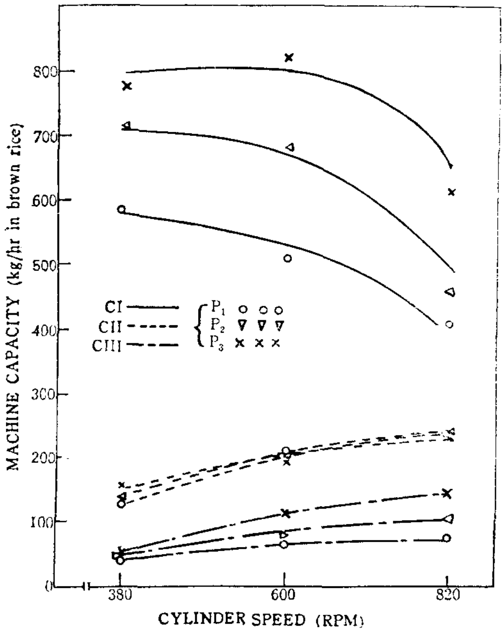


Fig. 18. Effect of cylinder speed on machine capacity by machine combniation (C) and counter-pressure(P).

to increase whitening efficiency. In addition, more attention needs to be given to the surface shape of the cylinder and its effect on capacity and recovery rates.

2) Electric power comsumption.

A 10 hp three phase electric motor was used to drive the machine. The electric power consumption required to mill unit amount of brown rice was computed the following formula:

$$KWH/kg = \sqrt{3}\ EI\ e_f \cdot p_f \cdot t/w$$

where E = voltage(V)
I = current in ampere (A)
e_f = motor efficiency
p_f = power factor of the motor
t = milling time (hr)
w = total weight of brown rice sample (kg)

The computed values representing each test run were subjected to statistical analysis(Appendix I-5).

For all machine combinations, an increase in the counter-pressure which gave a positive effect on radial pressure, decreased power consumption. In particular, combination III with the lowest level of the radial pressure showed a measurable decrease in power consumption as the counter-pressure was increased (Table 11 & Fig. 19). This may indicate that when pressure within the whitening chamber is below a certain level, even small increases in axial pressure improve milling efficiencies by a relatively large measure.

Power consumption was also affected by the cylinder speed, machine combinations and

Table 11. **Differences in means for power consumption between two machine combinations (C) at constant counter-pressure (P) and between two counter-pressure levels within machine combinations.**

kw/kg

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
P_1	0.01193	** (0.01652)	0.02845	** (0.05248)	0.08093	0.04043
Difference P_1 vs P_2	n.s. (0.00067)		n.s. (0.00201)		** (0.01886)	
P_2	0.01126	** (0.01518)	0.02644	** (0.03563)	0.06207	0.03326
Difference P_2 vs P_3	n.s. (0.00086)		n.s. (0.0008)		** (0.01210)	
P_3	0.01040	** (0.01596)	0.02636	** (0.02361)	0.04997	0.02891
Difference P_1 vs P_3	n.s. (0.00153)		n.s. (0.00209)		** (0.03096)	
Mean	0.01119		0.02708		0.0643	0.03420

LSD for difference between two counter-pressure levels within combination

5% : 0.00378
1% ··0.00508

LSD for the difference between two machine combinations at the same or different levels of counter pressure:

5% : 0.00636
1% : 0.01011

Note: $P_1=14.8$, $P_2=17.6$, $P_2=20.4 g/cm^2$
CI = Cylinder A + Screen A
CII = Cylinder B + Screen A
CIII = Cylinder B + Screen B

Table 12. **Differences in means for power consumption between two machine combinations (C) at a constant cylinder speed (S) and between two cylinder speed levels within machine combinations.**

	CI	Difference CI vs CII	CII	Difference CII vs CIII	CIII	Mean
S_1	0.01035	** (0.02352)	0.03387	** (0.05970)	0.09357	0.04593
Differeence S_1 vs S_2	n.s. (0.00440)		n.s. (-0.00865)		** (-0.03857)	
S_2	0.01075	* (0.00147)	0.2522	** (0.02978)	0.05500	0.03033
Difference S_2 vs S_3	n.s. (0.00173)		n.s. (-0.00309)		n.s. (-0.01059)	
S_3	0.01243	n.s. (0.00965)	0.02213	** (0.02228)	0.04441	0.02635
Difference S_1 vs S_3	n.s. (0.00213)		n.s. (-0.01174)		** (-0.04916)	
Mean	0.01119		0.02708		0.06433	0.03420

LSD for the difference between two cylinder speed levels whithin combination:

5% : 0.01185
1% : 0.01661

LSD for the difference between two machine combination at the same or different levels of cylinder speed:

5% : 0.01057
1% : 0.01451

Note: $S_1=380$, $S_2=600$, $S_3=820$ rpm
CI=Cylinder A+Screen A
CII=Cylinder B+Screen A
CIII=Cylinder B+Screen B

heir interactions. Combination I showed an increase in power consumption with increased cylinder speed. Combinations II and III, which are equipped with narrow pitch feed screw and had low levels of radial pressure, indicated decreased power consumption with increased cylinder speed (Table 12 & Fig. 20).

The comparison among combinations at the same or different levels of counter-pressure or cylinder speed indicated highly significant difference in power consumption between any two combinations

In summarary, it appears that the shape of the screen surface and pitch of the feed screw both have an important effect on power consumption.

Machine efficiency is defined as the capacity per horsepower-hour.

Fig. 21 indicates that large differences exist in horsepower required among machine combinations at every counter-pressure level and/or cylinder speed, particularly between combination I and combinations II & III. Within each machine combination, the power requirement increased with an increase in cylinder speed and counter-pressure. In combination I it was, however, slightly reduced at 820 rpm, at which the radial pressure was low. A direct proportional relationship was observed between power requirements and the radial pressure developed inside the whitening chamber.

Fig. 22, which shows the machine efficiency, illustrates the relationship between the machine capacity (discussed in a previous section) and the power requirement. It is evident that the counter-pressure had a minor but

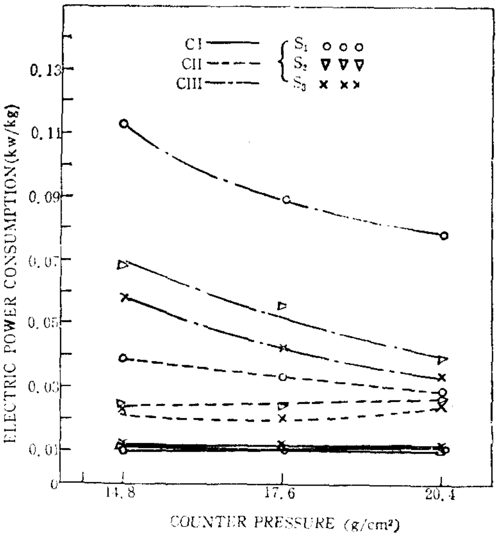


Fig. 19. Effect of counter-pressure on the energy consumption by machine combination (C) and cylinder speed (S).

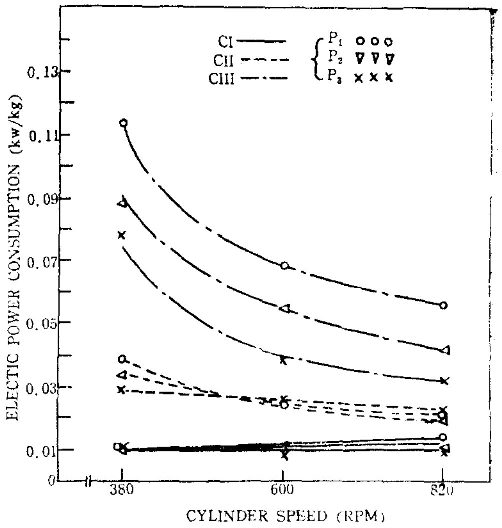


Fig. 20. Effect of cylinder speed on the energy consumption by machine combination (C) and counter-pressure (P).

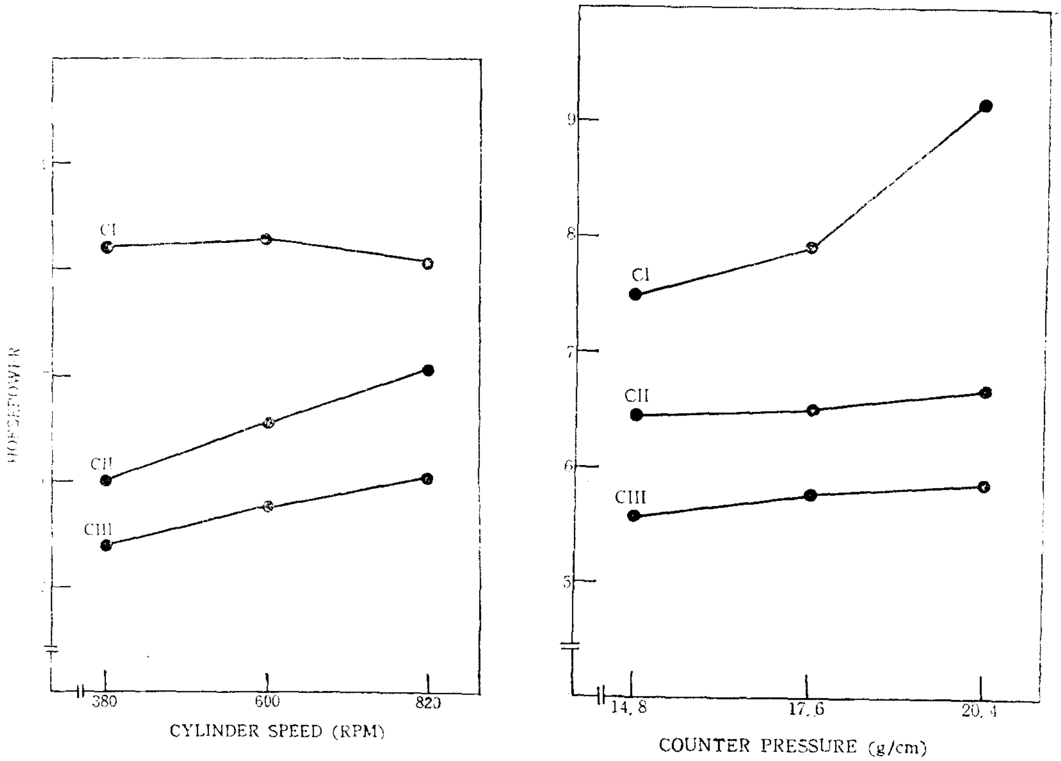


Fig. 21. Relationship of power requirement (HP) to cylinder speed and counter-pressure by alternative machine combination.

positive effect on the efficiency of the machine for all machine combinations, i. e., all radial pressure levels in the whitening chamber, The effect of cylinder speed was

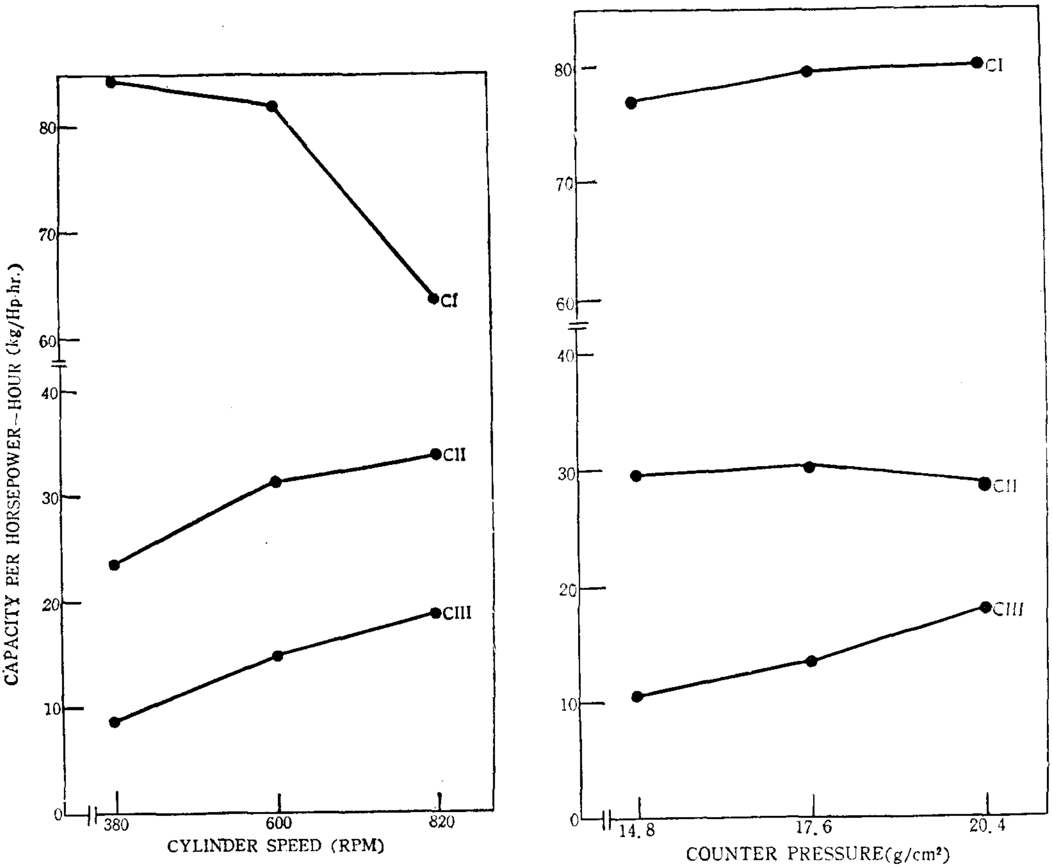


Fig. 22. Relationship of hourly capacity per horsepower to cylinder speed and counter-pressure by alternative machine combination.

not consistent, depending on the machine combination used. The efficiency increased with an increase in cylinder speed in combinations II and III but in combination I it was reduced, in particular, at 820 rpm. This may confirm that higher cylinder speeds and the high levels of radial pressure developed inside the whitening chamber cause slippage between the grain and the feed screw resulting inefficient power consumption.

In summary, machine efficiency is also largely affecected by the pitch of the feed screw and screen type. The interaction between machine combination (i.e. radial pressure level) and cylinder speed also has an important effect on machine efficiency.

E. Estimating an empirical characteristic curve for the rice whitening machine.

1) Radial pressure and head rice recovery.

We observed that development of radial pressure inside the whitening chamber was a function of the feed rate, screen type, counter-pressure, cylinder speed, and the processing stage of the grain. Not considered in this study are other factors such as the clearance between the cylinder and screen, the dimensions of the cylinder and screen, grain condition, etc. Further study is needed to estimate a functional relationship between pressure in the whitening chamber and all possible factors effecting pressure.

In the present study, an empirical equation explaining the relationship between* head rice recovery and average radial pressure was derived using obtained from each test run(Appendix II-1).

The dependent variable (Y_h), percent head rice recovery (decimal value), was expressed as the inverse of a quadratic equation of the independent variable, in this case radial pressure (X_p).

$$Y_h = \frac{1}{1.4385 - \overset{*}{0.2951} X_p + \overset{**2)}{0.1425} X^2_p} \quad (R^2 = 0.98) \quad (1)$$

According to this equation, head rice recovery remained nearly constant up to about 1.6kg/cm² of radial pressure. The variation created by the cylinder speed, counter-pressure level and screen type was relatively minor. Head rice recovery began to fall sharply when radial pressure was increased beyond about 1.6kg/cm². The variance around the observed mean also widened as radial pressure increased.

2) Radial pressure and machine capacity.

An empirical equation showing the relationship between radial pressure (X_p) and machine capacity (Y_c) was also obtained. A positive linear relationship was found between these two parameters within a limited radial pressure range of 1.0 to 3.5 kg/cm² (Appendix II-2).

$$Y_c = -305.83 + \overset{**2)}{373.37} X_p, \quad (R^2 = 0.88) \quad (2)$$

The variance of the capacity caused by cylinder speed, counterpressure and screen type was also gradually increased as radial pressure increased.

Equation (3), showing the relationship between head rice recovery and machine capacity was derived from equations (1) and (2).

$$Y_h = \frac{1}{1.2925 - 0.1587 \times 10^{-3} Y_c + 0.102 \times 10^{-5} Y_c^2} \quad (3)$$

The general form of this equation, which is the same as equation (1), implies that head rice recovery is partially governed by the capacity of the machine. If the quantity of milled rice produced per unit time is beyond a certain level, a drastic decrease in the head rice recovery will result.

3) Machine capacity and electric power consumption.

The correlation between machine capacity and electric power consumption was also estimated. The dependent variable (Y_e), electric power consumption, was expressed as an exponential function of machine capacity (Y_c), and shows an inverse relationship (Appendix II-3).

$$Y_e = 1.63 Y_c^{\overset{**}{-0.7786}} \quad (4)$$
$$(R^2 = 0.94)$$

4) An empirical characteristic curve

In order to examine the relationship among the radial pressure, head rice recovery, machine capacity and electric power consumption, an empirical characteristic curve was estimated by combining the figures obtained from equations (1), (2) and (4) into one chart (Fig. 23).

In this figure the capacity scale of the lower horizontal axis was developed using the linear relationship which exists between average radial pressure and machine capacity. The head rice recovery-radial pressure (H-Pr) curve constitutes the upper scale of the horizontal axis showing radial pressure and the left-hand vertical axis showing head rice recovery. The capacity-electirc power consumption (C-EC) curve involves the lower horizontal axis (capacity) and the right-hand vertical axis (power consumption). The dotted lines along the H-Pr curve show the variation caused by difference in cylinder speed, screen type and counter-pr-

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* The mean valus of the three replication for each test run were used in the estimation equation ($n=27$).

** Asterisk indicates significance level.

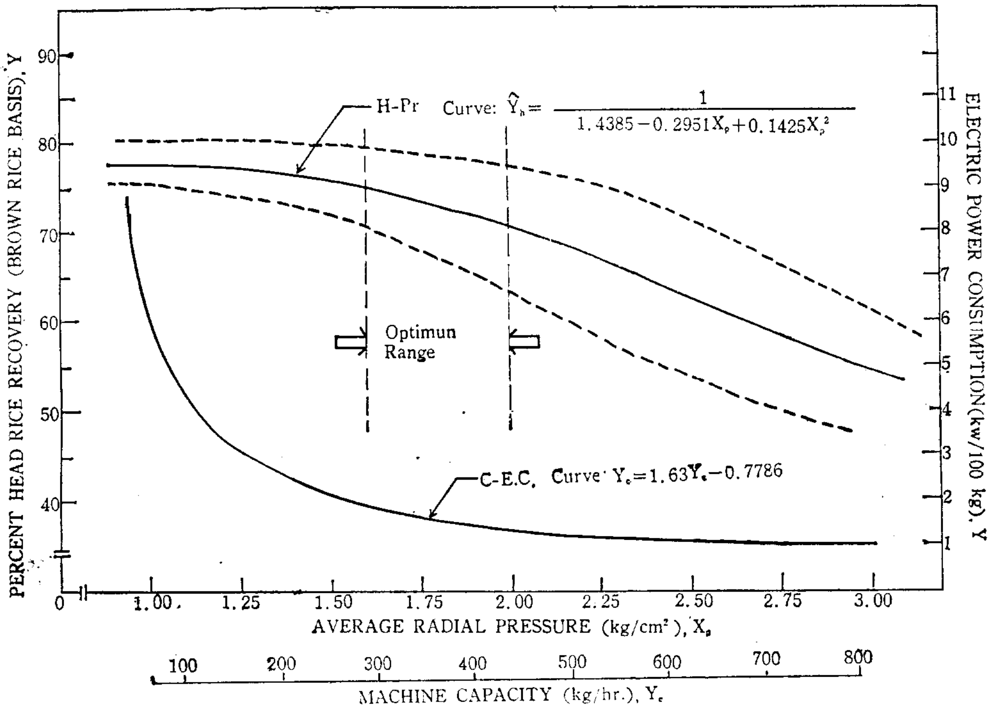

Fig. 23. An empirical characteristic curve for a rice whitening machine.

essure.

The general characteristic curve shows that when internal radial pressure is maintained at a low level, head rice recovery will be high but machine capacity will be limited and energy consumption per unit of output will be high.

In contrast, if radial pressure increases beyond the optimal range noted on the chart, a shap decrease in head rice recovery occurs without any significant in power consumption efficiency or machine efficiency. The power requirement increases more rapidly than capacity resulting in a decrease in machine efficiency. Therefore, to ensure high machine and milling efficiency, it will be important to maintain the pressure inside the whitening chamber within the optimal range by controlling the feed rate and the counter-pressure during machine operation.

The optimal range will be modified by changes in the physical or chemical characteristics of the grain being processed. It may shift to the right or left (with a simultaneous vertical movement in the H-Pr curve) as a result of changes in grain condition.

As shown in table 2, the fracture compressive strength of the hulled grain used in this test was 5.15kg for sound grain ($\sigma=0.63$) and 2.65 kg for chalky grain ($\sigma=0.36$), taking an average from 10 to 15 grains randomly selected from the sample.

Shimizu and Sakai[21] (1974) reported the bending load for long grain varieties of hulled and milled rice decreases with an increase in the moisture content. The observed fracture point under a bending load ranged from 0.32 to 1.83 kg for hulled rice and 0.09 to 1.45 kg for milled rice over a moisture range of 11.5 to 24.0 percent, respectively. The bending stress for milled rice was much lower than for hulled rice. Prasad and Gupta[17] concluded (1973) that yield point values and the maximum strength of the paddy grain ranged from 1.82 to 10.26 kg and 4.14 to 16.38 kg respectively, over a moisture range of 12 to 24 percent (d.b.) respectively. The rate of deformation also influences the energy absorbing capacity of grain. A paddy grain can absorb more energy when it is compressed at a high rate of deformation.

Parcenhetically, most operational manuals for rice milling machines do not provide information or grain factors. This is an important omission because grain factors often have a significant impact on milling performance and can be partially controlled through adjustments in the machine. Unfortunately, studies on the operational characteristics of processing machines and their relationship to grain characteristics and grain condition are very limited.

F. Other observations.

4) Byproducts and screen slot size

The quantity of byproducts produced by the whitening process is influenced by the degree of the bran removal (degree of whiteness of milled rice), the amount of broken grains produced and blown out with the bran through the screen openings, and the quantity of rice powder created from crushed grains and polishing during the milling process.

Analysis of the byproducts shows that combinations I and II, equipped with screen A which has relatively larger openings compared to screen B, produced more byproducts than combination III. In particular, the quantity of byproducts was appreciably higher for combination I at 380 rpm where head rice and total milled rice recovery were lowest(Fig. 24).

The quantity of broken grains contained in the byproducts is mainly attributable to the size of the slotted screen openings and the percent broken grains produced hulling and whitening. These factors affect total milled rice recovery.

It was noted there was a slight difference in percent broken grains mixed in byproducts (brown rice basis) between combinations I and II and about a one percent difference between combinations II and III. There existed

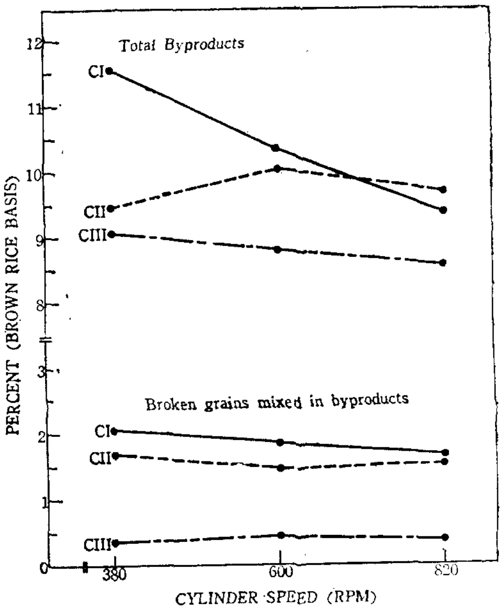

Fig. 24. Percent total byproducts produced and the broken grains (including brewers)mixed in byproducts.

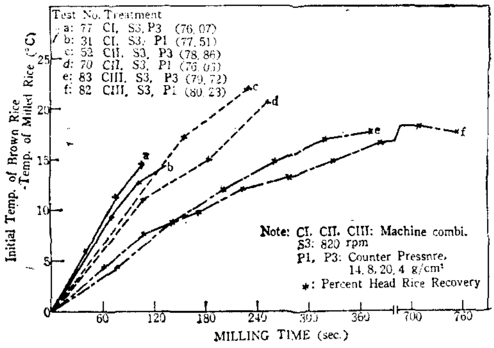

Fig. 25. Relationship between milling time and temperature of milled rice.

about one percent difference in total milled rice recovery at every level of cylinder speed between combinations II and III, although each showed nearly identical head rice recoveries.

2) Temperature of milled rice

"Satake" News Report[23] reported that the temperature of milled rice increases with total milling time and, if the difference between the initial brown rice temperature and the final milled rice temperature is greater than 10～15°C, it will affect head rice recovery and the taste of the cooked rice.

Referring to Fig. 9 (milling stage and radial pressure) and fig. 25, we note that a rise in milled rice temperature is related to the pressure inside the whitening chamber and the duration of each pass through the machine. A comparison among machine combinations at different counter-pressure levels indicated that a high radial pressure and extended milling time for each pass resulted in a rapid rise in temperature. The final temperature of the milled rice seemed to be largely influenced by both the milling time for each pass and the initial brown rice temperature.

The rapid rise in milled rice temperature is believed to have a close relationship with head rice recovery. The more rapid is the increase in temperature, the lower is head rice recovery.

結果및要約

精米機의 機械的 要因 및 作動條件 즉 시린더와 供給스크류 모양, 스크린形態, 시린더 속도와 시린더 軸 方向에 가해지는 반대抵抗등이 完全米收率, 搗精收率, 機械能力, 機械効率 및 精白室內의 壓力形成에 미치는 영향을 調査 分析하였다. 精白室內의 壓力은 Strain gage system 을 이용하여 측정하였다. 實驗結果는 다음과 같다.

1. 精白米의 表面狀態는 精白室내의 壓力造成에 영향을 주었다. 精白室 壓力은 첫번째 혹은 두번째 再 循環동안에는 비교적 낮고 機械種類에 따라 2～3회 혹은 3～6회 再循環 이후 最高에 달했으며 그 이후 다시 떨어졌다.

2. 시린더 供給 스크류피치는 精白室內의 壓力 白米의 質, 搗精收率 및 機械能力에 영향을 미치는 가장 重要한 要因으로 사료된다. 스크류피치가 4.8 cm일때는 2.3cm일때보다 精白室內의 壓力은 훨씬 높았으며 完全米收率은 현저히 감소하였다. 반면에 機械能力 및 機械効率은 前者가 훨씬 높았다.

3. 精白室을 構成하는 스크린 형태는 米糠除去効果에 중요한 영향을 미치는듯했다. 半球型모양의 突起가 있는 스크린의 경우 突起가 없는 스크린에 비해 機械能力과 効率이 높게 나타났으며 完全米收率이나 精白室의 壓力에는 별다른 차이가 없었다. 스크린및 시린더表面形態가 米糠除去効果, 機械効率 및 搗精收率에 미치는 영향에 관한 硏究가 권장된다.

스크린에 뚫여있는 직사각형모양의 구멍의크기는 搗精收率에 영향을 미치는 것으로 사료된다. 短粒種인 Japonica형 벼를 搗精하기 위하여 설계된 스크린의 구멍의 크기는 長粒種인 Indica형 벼 搗精에는 적당치 않은 것으로 사료된다.

4. 시린더 회전속도를 380 rpm에서 820 rpm까지 증가시킨결과 모든 機械條件에서 完全米收率이 증가하였다.

특히 供給스크류 피치가 큰경우 (4.8cm) 完全米收率은 820 rpm 일때가 380 rpm 일때보다 훨씬 높았다. 시린더 회전속도가 精白室壓力, 機械能力 및 機械効率에 미치는 영향은 供給 스크류 피치의 크기에따라 相反되는 給果를 보여주었다. 스크류 피치가 2.3cm인 경우 시린더 속도와 精白室壓力, 機械能力 및 機械効率사이에는 각각 정비례 관계가 있었으나 스크류 피치가 4.8cm인 경우 이들 사이에는 반비례관계를 보여주었다.

本 實驗結果 長粒種인 Indica 형 벼의 完全米收率 및 機械効率을 증가시키기 위해 시린더 회전속도를 현재 수준인 500～600 rpm 에서 800rpm 수준으로 증가시키고 반면에 供給 스크류 피치를 현재 사용되고있는 4.8cm이하로 줄이는 것이 권장된다.

5. 시린더 軸方向에 加하는 반대저항을 증가 시킬수록 精白室內의 壓力, 機械能力과 機械効率은 증가했으며 完全米收率은 감소했다.

6. 精白室內의 壓力은 完全米收率, 機械能力 및 電力 消耗와 密接한 관계가있다. 本 實驗에서 얻어

진 精白機 特性曲線에 의하면 精白室內의 壓力(Xp)과 完全米收率(Yh) 및, 機械能力 (Ye) 사이에는 각각 다음과 같은 관계가 있었다.

$$Yr=\frac{1}{1.4385-\overset{*}{0.2961}\,Xp+\overset{**}{0.1425}X^2P}\qquad (R^2=0.98)$$

$$Yc=-305.83+\overset{**}{374.37}Xp\qquad (R^2=0.88)$$

그리고 機械能力(Yc)과 電力消耗(Ye) 사이에는 다음과 같은 指數함수의 관계를 보여주었다.

$$Ye=1.63Yc^{\overset{**}{-0.7786}}\qquad (R^2=0.94)$$

이들 관계에 의하면 精白室 壓力이 일정수준(1.6~2.0*kg/cm²*) 이상으로 증가하면 完全米 收率은 2차함수적으로 감소하며, 機械能力은 1차함수적으로 증가하고, 白米의 단위생산량당 電力消耗에는 變化가 거의 없음을 알수있다. 반면에 壓力이 일정수준 이하로 떨어지면 電力消耗는 급격히 증가하고 機械能力은 1차함수적으로 감소하며, 完全米收率은 별다른 증가가 없음을 말해준다.

그러므로 이미 주어진 정백기의 경우 運轉中에 精白室內의 壓力을 最適水準(1.6~2.0*kg/cm²*) 으로 유지시키기 위해 穀物의 供給量과 出口則 反對抵抗을 穀物의 상태 특히 穀物의 強度를 고려하면서 조정하여야 할 것이다.

또한 精白室內의 壓力水準은 再循環回數와 密接한 관계가 있었다. 精白室內의 壓力이 높으면 높을수록 再循環回數는 감소되었다. 격심한 完全米 감소를 피하기위해 최소한 3번 이상의 再循環이 요구된다.

7. 白米의 온도상승율은 精白室의 壓力 및 完全米收率과 密接한 관계가 있었다. 온도 상승율이 높으면 높을수록 宗全米收率은 감소하는 경향을 보였다.

References

1. Autsey, M.S. 1953. "Effect of Processing Vasiables on Milling Yields, "Proceedings, Rice Technical wroking Group, Beaumont, Taxas, Jan. P. 17.
2. F.A.O. 1956. "Report of the Meeting of the Ad Hoc Working Group on Storage and Processing of Rice, "held at Calcutta, India. November, pp. 36-39.
3. Mukumoto, T. 1959. Agricultural Machinery and Implements in Japan. Agriculture, Forestry and Fisheries Productivity Conference. pp.22-39.
4. Matsuda, R. and Ezaki, H. 1962. Grain Conditioning and Forage Harvesting Machines (Illus. Farm Machines Sev. Vol. 6) Shin-norinsha. Co., Ltd., Tokyo. pp. 2-16.
5. Wasserman, T. 1962. "Remoistening of Overdried Milled Rice, High-temperature Sample Drying and Effect of Time Lags Between Drying and Milling. "Proceedings, Rice Technical Working Group, Houston, Texas, Feb. p. 29.
6. Faulkner, M.D., Wratten, F.T. and Miller, M.F. 1967. "The Effect of Milling Quality of Rice due to Various Harvest Moisture Content.". 59th Annual Progress Report, Rice Experiment Station, Louisiana. 98-102.
7. Bhatia, K., Wratten, F.T. and Faulkner, M.D. 1968. "Effect of Environmental Conditions During Milling on Breakage of Rice Grains." 60th Annual Progress Report, Rice Experiment Station, Louisiana, pp. 95-112.
8. Kim, N.K. 1970. Rice and Barley Milling. Korean Grain Processing Technology Institute.
9. Shin K.S. 1971. "Comparative Performance Test of Rice Whitening Machines," Annual Progress Report, the Farm Machinery Utilization and Research Inst. O.R.D. Korea. pp. 433-449.
10. Stipe, D.R., Wratten, F.T. and Miller, M.F. 1971. "Effects of Various Methods of Handling Brown Rice on Milling and

Other Quality Parameters," 63rd Annual Progress Report, Rice Experiment Station, Louisiana, pp. 79-96.

11. ____________ 1972. "Factors Influencing the Rice Milling" Agricultural Engineering Vol. II, Dept. of Agricultural Engineering, College of Agriculture, S.N.U., Korea, pp.19-22.
12. ____________________ 1972. "Drying Test," 64th Annual Progress Report, Rice Experiment Station, Louisiana, pp.316-153
13. Wimberly, J, 1972. "Review of Storage and Processing of Rice in Asia." Agricultural Engineering Dept., IRRI, paper no. 72-01.
14. Aroma, V.K., Henderson, S.M. and Burkhardt, T.H. 1973. "Rice Drying Cracking versus Thermal and Mechanical Properties." Trans. of the A.S.A.E. Vol. 16, No. 2, pp. 320-327
15. Convanich, A. and de Padua, D.B. 1973. "Performance Characteristics of Three Types of Laboratory Rice Mill," Philipppine Agriculturalist, Vo. LVI, No. 9 & 10, pp. 359-373.
16. Juliano, B.O. 1973. "Biochemical Properties of the rice grain in relation to milling land eating pualities." Post-harvest Rice Technology. Compilation of Lectures at the Regional Training Course, University of the Philippines, April 1-30, IDRC, Singapore, 9. pp. 38-46.
17. Prasad, S., Gupta, C.P. 1973. "Behavior of Paddy Grains under Quasi-Static Ccmpressive Loading," Trans. of the A.S.A.E., Vol. 16 No. 2 pp. 328-330.
18. Samson B.T. and Duff, B. 1973. "The Pattern and Magnitude of Field Grain Losses in Paddv Production." IRRI Saturday Seminar, July 7.
19. _________________1973. "Rice Drying and Processing," 65th Annual Progress Report, Rice Experiment station, Louisiana, pp. 95-112.
20. IRRI, Agricultural Engineering Dept. 1974. Evaluation of Commercially produced machinery (Different types of hullers and polishers). Semiannual Progress Report No. 19 pp. 25-26.
21. Shimizu, H. and Sakai,T. 1974. "The Research of the Dynamic Characteristics of the Grain of Rice by the Method of Bending Load," Society of Agr. Machinery, Jan, Vol. 36, No. 1, pp. 108-113.
22. ____________Roberts, R.L., McGready, R.M., Bailey, G.F. 1974. "Changes in Yields, Milling Time and Conditions, and Energy Requirements in Commercial-Type Rice Mills," Proceedings, Rice Technical Working Group.
23. "SATAKE" Technical News No. 15, 20 and 21. SATAKE Engineering Co., Ltd., Tokyo.