# 搗精收率과 性能向上을 爲한 研究(Ⅱ)

—벼의 精白過程에 對한 實驗的 研究—

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# Study on the Improvement of Milling Recovery and Performance(Ⅱ)

—Experimental Study on Rice Whitening Mechanism—

## 摘 要

이 研究는 精白過稅中에 發生하는 搗精產物 즉, 精白米, 米糖, 碎米等의 發生을 調查함으로써 玄米의 精白이 進行되는 過程을 밝히고자 함이다.

本 實驗에서는 噴風摩擦式 精米機를 使用하였으며, 精米機의 롤러 回轉速度를 850rpm으로 固定하고 出口抵抗은 3가지 水準으로 變化시켰다. 한편 이 實驗에 使用된 벼는 밀양 23號로써 전형적인 통일계品種의 一種이다. 每循環마다 生產되는 精白米 및 副產物로부터 sample를 採取하여 米糖, 大小碎米, 完全米 및 搗精收率을 分析하였다.

實驗結果를 要約하면 다음과 같다.

1) 全體糖層의 75%가 2번째 循環以內에서 除去되었다. 糖層除去率은 出口抵抗에 크게 影響을 받으며, 높은 出口抵抗에서 높은 糖層除去率을 보였다.
2) 大碎米의 發生은 대부분 精白過程 初期段階에서 이루어 졌으며, 完全米로 부터의 새로운 碎米發生은 循環이 反復됨에 따라서 急激히 減少하였다. 出口抵抗과 大碎米發生과의 關係는 出口抵抗이 增加할수록 大碎米의 發生도 增加하였다.
3) 米糖集積器로부터 採取한 sample에서 測定한 小碎米는 量的으로 다른 搗精產物에 比해 적은 편이었다. 8%의 米糖이 除去된 後 小碎米는 玄米重量의 0.6% 以下로 나타났다.
4) 搗精收率과 完全米收率은 어느 정도 出口抵抗의 影響을 받는 것으로 나타났다. 出口抵抗이 增加함에 따라서 특히 完全米收率은 減少하는 傾向을 나타냈기 때문에 白米의 質的低下를 막기 위해 높은 出口抵抗(本 實驗結果에 依하면 85g/cm²)을 使用하는 것은 不適當한 것으로 思慮된다.
5) 白度計의 測定値와 米糖除去程度(精白度) 사이에는 高度의 相關關係가 있었다.

그러므로 "KETT"製 白度計는 精白米의 精白度를 判明하는데 便利하게 使用될 수 있다.

## Ⅰ. Introduction

The milling process has been considered one of the sources of the greatest grain losses among all the processes of rice post-production system. According to the previous work, the total grain loss incurred during milling

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process was assessed to be on average 4～6% of the total yield, major sources of which were classified into improper premilling and milling factors and overmilling practice. It is also a general understanding that these factors have additional effect to a great extent on the quality of the milled rice, such as the amount of the broken kernels in the final product.

In attempting the investigation of a new design of problem-bounded whitening machine and/or the improvement of their operational conditions, it is necessary to understand the cause-and-effect relationship of the whitening process. Problems are becoming much more complicated than it has been because of the introduction of many high yielding Indica-type new varieties which have different physical and mechanical characteristics compared to conventional varieties. In addition, many domestic manufacturers currently produce a variety of whitening machines, to which they claim that their machines were designed to reduce grain losses for the processing of the new varieties. However, no real answer justifying their claims is presently available.

In these respects, a research work was initiated to evaluate and develop a rice whitener which can increase the quality and quantity of milled rice with Indica type rice variety and that will reduce grain losses. The specific objectives are as follows;

1) to investigate the changes in degree of bran removal, broken kernel occurrence, milled rice recovery, head rice recovery and whiteness of milled rice according to the increase of number of passes (recycling times).

2) to understand the real mechanism of the occurrence of broken kernels when milling is performed with Indica-type rice variety and whitening macine with jet-air blower which is the one of the most popular type of rice milling machines in Korea.

## Ⅱ. Review of Literature

There are many factors affecting the milling performance and milling recovery. Chung, et al (1980) reported in connection with the overall assesment of rice milling grain loss that the sources of grain losses can be purposely classified into three: the premilling and milling factors and overmilling practice. These three sources were contributed to about the same degree of grain losses. However, the report emphasized that, to reduce the grain losses during milling process of commercial mills, milling factors such as machine components and operational method should be improved. Juliano (1973) reported that with the horizontal friction type whitening machine, an increase in counter pressure with a given cylinder speed resulted in an increase in hourly capacity as well as efficiency of the machine. Matthews and Spadaro (1974) reported that higher counter pressure resulted in a greater removal of bran and breakage. Two passes were superior to one pass in effecting the some degree of bran removal with less breakage. No and Choi (1976) investigated the mechanical and operational factors affecting the efficiency of rice polishing machine. They reported that an increase in the counter pressure level produced a negative effect on the head rice recovery with an increase in radial pressure, capacity, and machine efficiency. When radial pressure increased above a certain range (1.6 to 2.0kg/cm$^2$), head rice recovery decreased in a quadratic relation with a linear increase in capacity but without any decrease in power consumption per unit of brown rice. On the other hand, if radial pressure was below the range, power consumption increased dramatically with linear decrease in capacity but without siginificant increase in head rice recovery. The higher the radial pressure was, the fewer the number of passes required but with decreased head rice recovery. The total number of passes should be increased to more than three to avoid decrease in head rice recovery. A study to investigate the operational characteristics of a jet-air-pressure type rice whitening machine was carried out by Chung, et al (1980). According to this study, the counter pressure setting was the most important factor which affected the head rice recovery significantly. And the roller speed significantly affected the milling capacity and milling efficiency but did not affect the head rice recovery.

Juliano (1973) reported that the optimum cylinedr speed for horizontal friction type with jet-air blower was 600 to 800 rpm. Autrey, et al (1955) working with both medium grain and long grain rice, reported that only about 1/5 of the total breakage occurred during the time period required to remove 75% of the total bran produced. When the milling time extended to remove the remaining 25% of the bran, about 4/5 of the breakage occurred. However, Matthews, et al (1974) working with both long and medium grain rice, reported that almost all of the breakage occurred in the first 10 sec of milling, about 70% of the bran was removed in the first 10 sec. And bran removal continued although at a decreasing rate for the entire milling period.

Conditions of grain at harvesting affects on milled rice and head rice recoveries. Smith, et al (1938) reported that delayed harvesting, which led to increased breakage of individual grain, was accompanied by decreased moisture content of the paddy rice. Matthews, et al (1975) found by X-ray photographs that the combine harvested samples averaged over 5 per cent points more cracked and broken rough rice kernels than the hand harvested samples.

Cracking and breakage of grain occurred during drying result in unfavouable effect on milling. Faulkner, et al (1967) found large difference in milling yields resulting from different methods of drying and pointed out the benefits of controlled drying over sun-drying.

Kunze, et al (1971) reported that the tensile strength of the rice kernels gradually decreased as the time of rexposure to moisture-adsorbing conditions increased even before physical fissures appeared. Therefore, even the kernels which had not developed cracks were more susceptible to breakage after exposure to adverse environmental conditions. The radiating configuration of the outer starchy cells of the endosperm made breakage very easy in the grain. The risk of such breakage was much greater when impact exerted along the side of grain rather than at the end. It has been observed that breakage during the manual beating of the grain even at a moisture content of 20%, is much greater than in certain types of mechanical threshing where the force is applied to the end of grain.

## Ⅲ. Materials and Method

### A. Milling system

Milling system at the College of Agriculture, Seoul National University was used in this experiment. The elevation view and schematic flow diagram of SNU milling system are shown in Fig. 1 and Fig. 2, respectively, of the previous work[1], which was undertaken independently from this study. The specificiation of the rice whitening machine used in this experiment is also outlined in Table 1 of the previous work[1].

### B. Materials

The paddy rice used for this experiment was the same as that for the previous work. The quality and the physical properties are listed in Table 2 of the previous work[1].

### C. Methodology

Roller speed was kept at 850 rpm which was specified by the manufacturer. The counter pressure was varied with 3 levels, which were selected by lowering the scaled control lever position; Level 1 (low) for the pressure corresponding to 49 g/cm², level 2 (middle) to 67 g/cm² and level 3 (high) to 85 g/cm². The feed-gate valve was fully opened and thus constant flow-rate was maintained, since change of counter pressure had practically no effect on flow-rate according to the preliminary work[1].

One factor experiment with 3 levels was conducted with two replications. [Table 1]

There are three by-product collectors in the SNU milling ystem. One of these is the cyclone collector which is connected to the whitening machine. The second collector is placed on recycling path toward the whitener and collects the material passing through the screen with 13 mesh opening. The last collector is placed on outgoing path toward the milled rice bin and collects the material passing through 13-mesh screen.

**Table 1. Experimental design, conditions of brown rice and ambient air condition when the experiment was conducted**

| Replication | Treatment | Moisture content of brown rice (%) | Ambient conditions at test | | Remark |
|---|---|---|---|---|---|
| | | | Temperature (°C) | Relative humidity (%) | |
| I | $R_2$ $C_3$ | 14.8 | 23.4 | 81.3 | M.C. mean = 14.7%<br>S.d. = 0.10<br>range = 14.6—14.8% |
| | $R_2$ $C_2$ | 14.7 | 23.1 | 79.5 | Temp. mean = 22.37°C<br>S.d. = 1.54<br>range = 20.6—23.4°C |
| | $R_2$ $C_1$ | 14.6 | 20.6 | 90 | R.H. mean = 83.6%<br>S.d. = 5.62<br>range = 79.5—90% |
| Ⅱ | $R_2$ $C_1$ | 14.6 | 23.3 | 84.5 | M.C. mean = 14.5%<br>S.d. = 0.10<br>range = 14.4—14.6% |
| | $R_2$ $C_2$ | 14.5 | 22.9 | 70 | Temp. mean = 23.17°C<br>S.d. = 0.22<br>range = 22.9—23.3°C |
| | $R_2$ $C_3$ | 14.4 | 23.3 | 72 | R.H. mean = 75.5%<br>S.d. = 7.86<br>range = 70—84.5% |

Note $R_2$=Roller speed, 850 rpm
C=Counter-Pressure settings in g/cm² (1 ; 49, 2 ; 67, 3 ; 85)

During whitening process, the materials collected in three by-product collectors included not only bran but also some broken kernels and small particles of ground rice. To recover these small broken kernels within the collected materials, the samples were taken from three by-product collectors and measured the content of small broken kernels collected together with the bran. In addition, sample of final product resulting from each passes of a whitening process was taken to evaluate the content of large broken kernels, head rice recovery, milled rice recovery and whiteness of milled rice.

## D. Terminologies regarding milling products

### 1) Bran removal

In this experiment, two kinds of the bran removal were defined. The first one was bran removal in each pass (BRP) and another was cumulative bran removal (CBR), each of which was obtained as follows;

$$BRP = \frac{\text{weight of bran removal from brown rice}}{\text{weight of brown rice used for one test}}$$

$$\frac{\text{in each pass}}{\text{run}}\times 100(\%)$$

$$CBR=\frac{\text{weight of cumulative bran removed from brown rice}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

Small broken kernels, contained in milling by-product, were separated out by the 20-mesh screen and only the throughs were accounted for pure bran.

**2) Occurrence of broken kernels**

Experimental milling system made it possible to collect large broken kernels and small broken kernels separately. The former was contained in the whole milled rice collected at the rice tank. On the other hand, the latter was contained in the bran collected at by-product collectors and cyclone collector.

The followings are the defined terms related to broken kernel occurrence;

Large broken kernels in milled rice in each pass (BKM):

$$BKM=\frac{\text{weight of large broken kernels produced in each pass}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

Cumulative large broken kernels in milled rice (CBKM):

$$CBKM=\frac{\text{weight of cumulative large broken kernels}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

Small broken kernels in bran in each pass (BKB):

$$BKB=\frac{\text{weight of small broken kernels in each pass}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

Cumulative small broken kernels in bran (CBKB):

$$CBKB=\frac{\text{weight of cumulative small broken kernels}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

3) Milled rice recovery

Milled rice recovery (MR) in per cent was defined as follows:

$$MR=\frac{\text{weight of milled rice}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

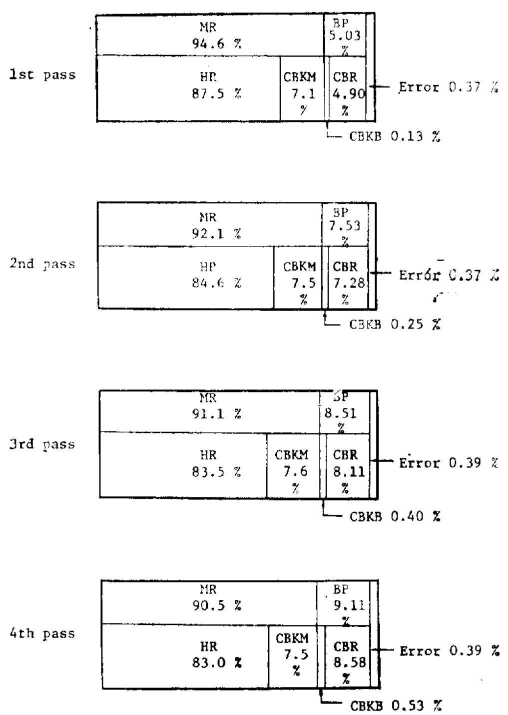
4) Head rice recovery

Head rice recovery (HR) in per cent was defined as follows:

$$HR=\frac{\text{weight of head rice}}{\text{weight of brown rice used for one test run}}\times 100(\%)$$

5) Whiteness of milled rice

"KETT" whiteness meter used to measure the whiteness of milled rice. Three samples were taken for each milling pass and measured with "KETT" whiteness meter.




MR : Milled rice recovery
HR : Head rice recovery
CBKM : Cumulative broken kernels in milled rice
BP : By-product
CBR : Cumulative bran removal rate
CBKB : Cumulative broken kernels in bran

**Fig. 1. The relative amounts of components of milling products and their changes as the number of whitening passes increased.**

## Ⅵ. Results and Discussion

### A. Overall milling process analysis

Fig. 1 shows an example of the milling process how it was progressed as the number of passes increased. From the figure it can be seen that after the 1st pass the brown rice kernels underwent a partial removal of bran and production of large and small broken kernels. It is particularly noted that the large broken kernels produced after the 1st pass amounted to 7.1% of brown rice. However, 4 percentage points out of such large broken kernels were caused in the premilling stage as shown in Table 2 of previous work[1] Even with this point in mind, we can easily understand that the large broken kernels produced in the 1st pass are considerably greater than those in the subsequent passes.

When the milled rice obtained at the end of 1st pass was sent to the 2nd pass, following mechanisms were observed a) a part of bran layer remaining on the whole kernels was removed, b) some of whole kernels were broken into large and/or small broken kernels, c) large broken kernels already formed in a previous pass were cracked and/or ground to produce smaller particles such as small broken kernels and bran dust. The small broken kernels and bran dust were collected in by-product collectors and whole and large kernels were sent to the next pass. After the 4th pass the total amount of large broken kernels were reduced by about 0.1% point from 7.6 to 7.5%. This may indicate that the amount of large broken kernels which were subject to further breakage should be nearly balanced with the amount of the newly formed large broken kernels from the whole grain.

### B. Bran removal rate

Cumulative bran removal during the whitening process is shown in Fig. 2. It is evident that the higher the counter pressure, the faster the bran removal rate. About 8% bran removal from the

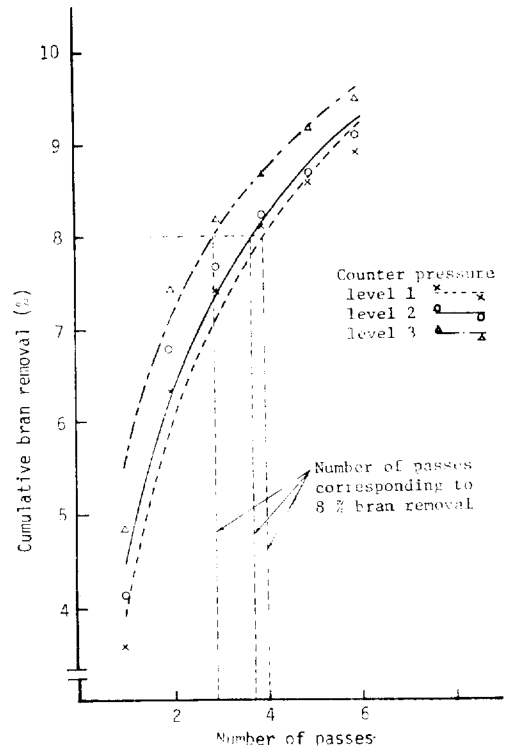



**Fig. 2. Cumulative bran removal vs. number of passes**

brown rice was obtained after 4.0 passes with the counter pressure set at level 1 (49g/cm²), 3.7 passes with the level 2 (67 g/cm²) and 2.9 passes with the level 3 (85 g/cm²), as indicated by the dotted lines in the figure. Within the counter pressure range varied in this study, about 7 to 8% bran removal was obtained after 3 passes.

Fig. 3 shows that the rate of bran removal from the brown rice was not proportional to the number of passes. In other words, the bran removal rate was steadily decreased as the recycling pass was repeated.

Most of bran was removed from the brown rice during the 1st and 2nd passes within the counter pressure range used in this study. Colour of by-product gradually changed from dark brown to white as the number of passes increased. Even though this study did not measure the contents of the ground endosperm and/or embryo in the

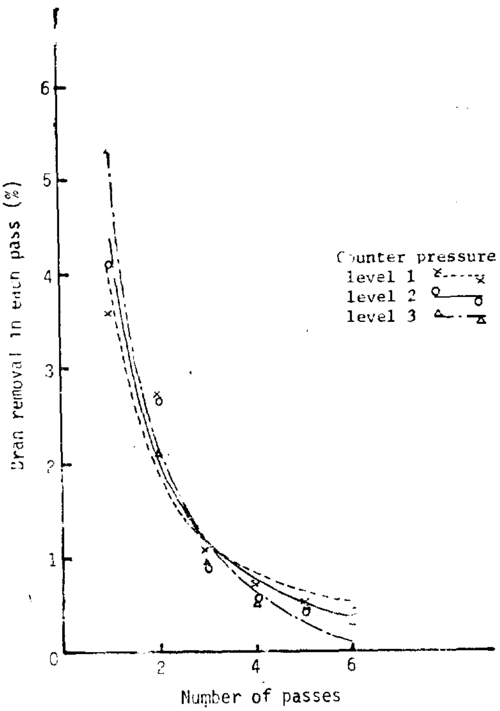



**Fig. 3. Bran removal in each pach pass vs. number of passes**

by-product, it is easily understood by this colour change that a considerable portion of these edible element were abandoned into waste even before reaching at 8% bran removal. And rice bran is relatively soft compared to the hard endosperm. However, it was very difficult to find out stopping point at which one would generally expect well milled rice and stop milling operation. Thus it is believed how important it is to develop the whitening machine and/or method of milling which would enable to reduce the removal of edible rice at the completing stage of milling or to prevent the overmilling.

## C. Occurrence of broken kernels

Broken kernels which was produced during milling process were classified into large broken kernels and small broken kernels. The small broken kernels were defined in this study as those passing through the #13-mesh screen but retained on the #20-mesh screen. Thus, #20-mesh was used to experimentally determine the amount of small broken kernels in the by-product collectors.

On the other hand, the large broken kernels are the broken kernels which were included in the milled rice. Therefore, these kernels are large enough not to pass through the separation screens that set in the path to be retained within the slotted screen of the whitener. The Burrow's sizing device was used to separate the broken kernels included in the milled rice.

**1) Large broken kernels:** Fig. 4 shows the relationship between the occurrence of large broken kernels in milled rice in each recycling pass and the number of passes. The amount of large broken kernels in milled rice was large in the begining of milling process and diminished as the increase of the number of passes. This

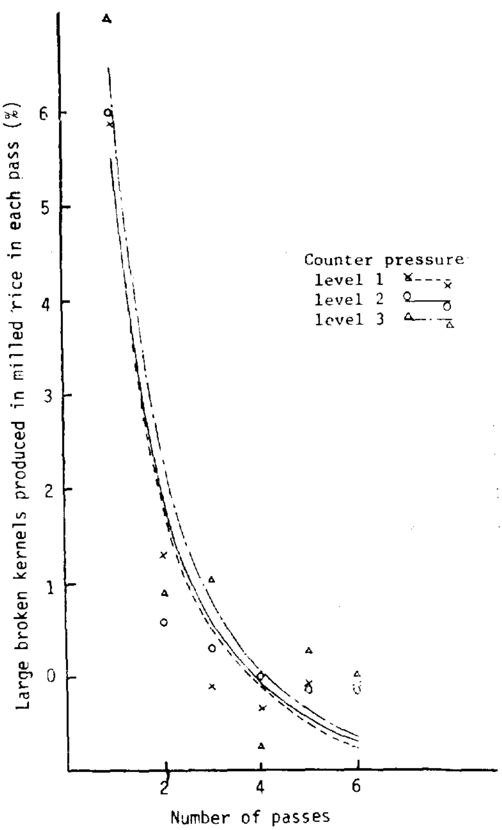



**Fig. 4. Large broken kernels produced in milled rice in each pass vs. number of passes**

result is constrast to the study by Autrey, et al (1955), who reported that only about 20% of the breakage occurred during the time period of 75% removal of bran and 80% of the breakage to remove the rest of the bran. A further study is recommended to identify the problem, since it is important in view of practical application.

In particular, it is remarked that at the stage of completing the bran removal the new formation of the large broken kernels was almost balanced with the diminishment of the previously formed large broken kernels, as shown in Fig. 1 and 4. Even though the trend stated above was more or less the same for all the counter pressure levels applied, the total amount of large broken kernels at the high counter pressure was greater than those at the middle and low counter pressure levels, as seen clearly from Fig. 5. This fact may indicate the importance why the pressure within the whitening chamber should be kept at a lower level, if possible, to reduce the formation of broken kernels.

2) **Small broken kernels:** It is presented in Fig. 6 the relationship between the occurrence of small broken kernels in bran in each recycling pass and the number of passes. The occurrence of the small broken kernels was varied irregularly as the recycling was continued. Nevertheless, general trend obviously indicated that the production of small broken kernels in each pass decreased as the number of passes increased, and particularly with the higher counter pressure setting.

Fig. 7 shows cumulative small broken kernels in bran. The cumulative small broken kernels increased linearly with the increase of the number of passes, however, did not show significant difference with the variation of counter pressure. It is interesting to note that the cumulative small broken kernels up to the completion of milling

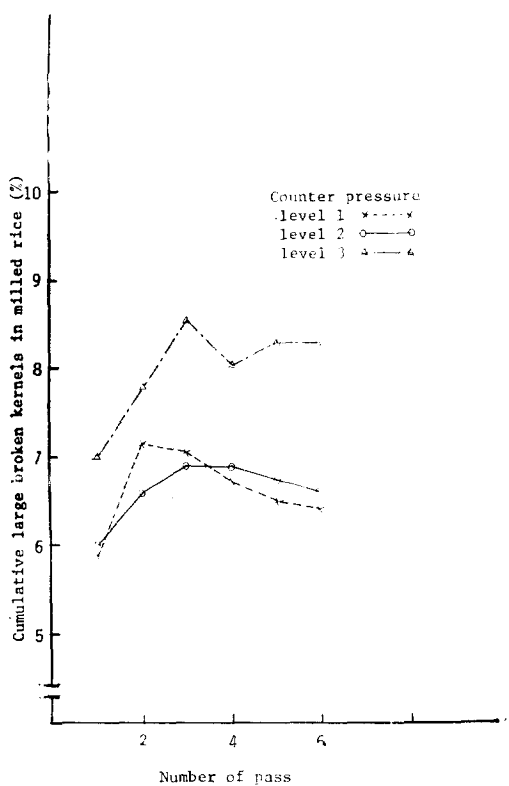



**Fig. 5. Cumulative large broken kernels in milled rice vs. number of passes**

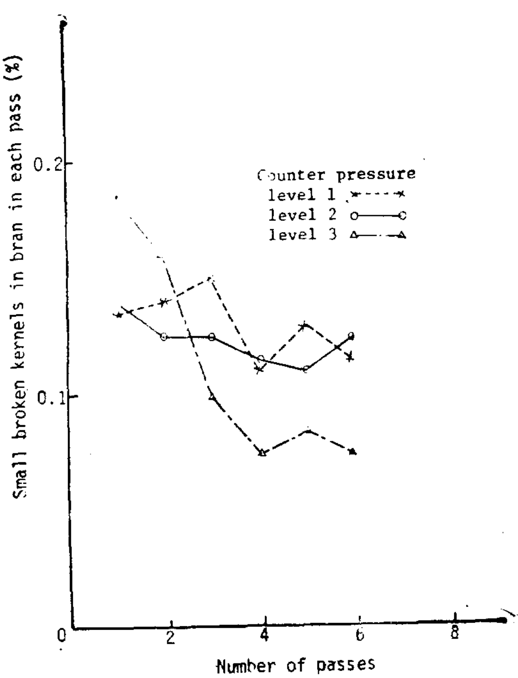



**Fig. 6. Small broken kernels in bran in each pass vs. number of passes**

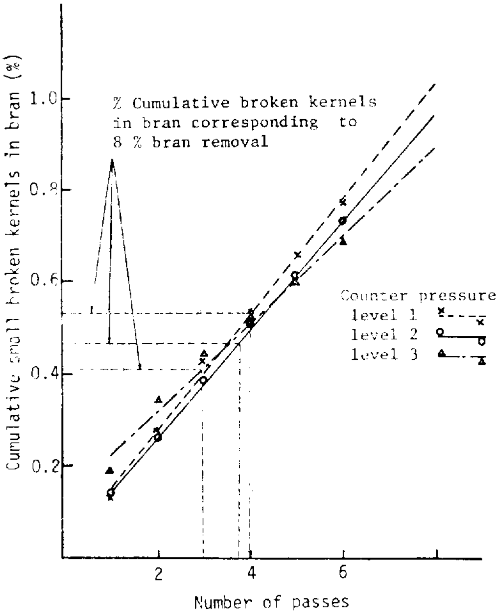



**Fig. 7. Cumulative small broken kerenls in bran vs. number of passes**

were greater when the lower counter pressure level was applied.

Cumulative small broken kernels corresponding to 8% bran removal was 0.41% with level 3, 0.46 % with level 2, and 0.53% with level 1.

Cumulative small broken kernels were quite a small, in general, less than 1% of brown rice. But it cannot be overlooked because the small broken kernels are treated as the unrecoverable food in actual milling practice, and thus attributed to the direct cause of reducing the milled rice recovery.

## D. Milled rice recovery

The variation of milled rice recovery, when the whitening process repeated, is presented in Fig. 8. The higher the counter pressure, the faster the rate of bran removal. However, the effect of the counter pressure on the milled rice recovery corresponding to 8% barn removal was very small. This resulted partly from the fact that the differences in the occurrence of the small broken kernels among three counter pressure

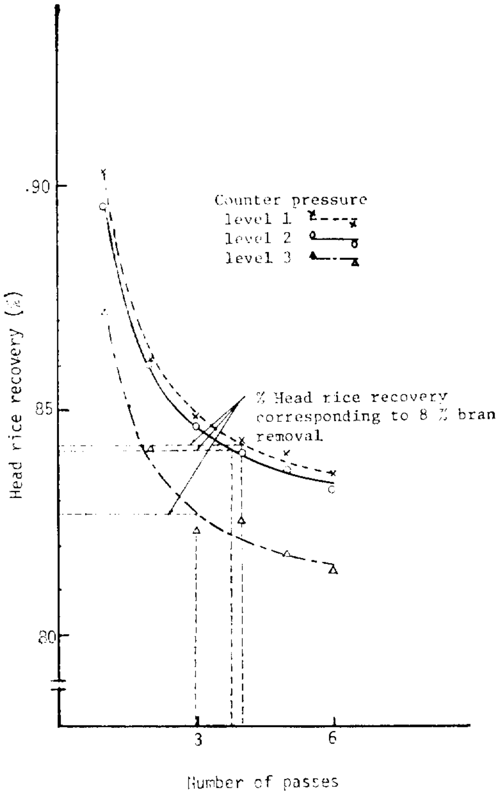



**Fig. 8. Milled rice recovery vs. number of passes**

levels were quite small. This result is identical to that of the previous study conducted by Chung, et al (1980).

## E. Head rice recovery

Fig. 9 shows the relationship between head rice recovery and number of passes. Head rice recovery was rapidly decreased as the number of passes increased.

Head rice recovery was 84.2% with the low level of counter pressure, 84.1% with the middle level and 82.7% with the high level. The difference in head rice recoveries of two lower counter pressure was very small. But there was 1.4 percentage point difference between the high level and two lower levels of counter pressure. This fact emphasizes the milling with high pressure is very objectionable to reserve the quality

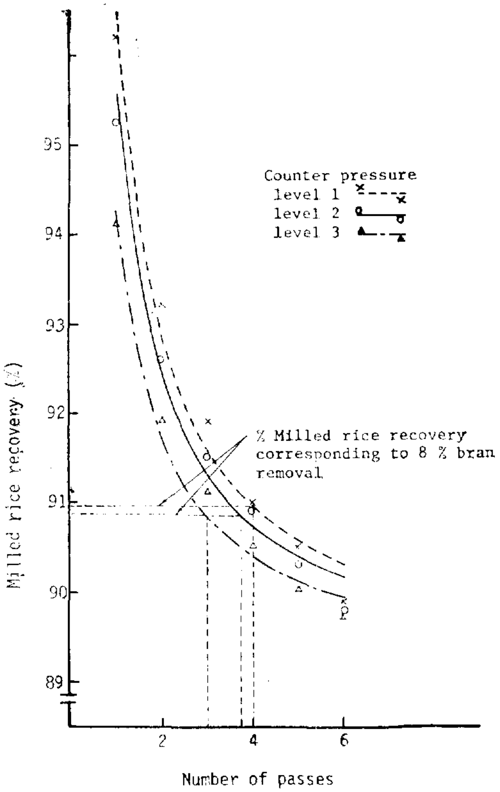



**Fig. 9. Head rice recovery vs. number of passes**

of milled rice. It is noted that for all the counter pressure levels applied, the head rice recoveries found in this study were within the range of 82.5 to 84.5% at 8% bran removal, which should be extraordinarily high compared to those of commercially milled rice. It is believed that this result is due to the high quality of rough rice used in this study.

### F. Whiteness of milled rice

The whiteness of milled rice at each pass was measured by "KETT" whiteness meter to check the relationship between the degree of the bran removal and the whiteness of milled rice.

Fig. 10 shows that whiteness of milled rice has linear relationship with the degree of the bran removal. The whiteness of milled rice at 8% bran removal was in the range of 40—41.

By regression analysis, very acceptable regres-

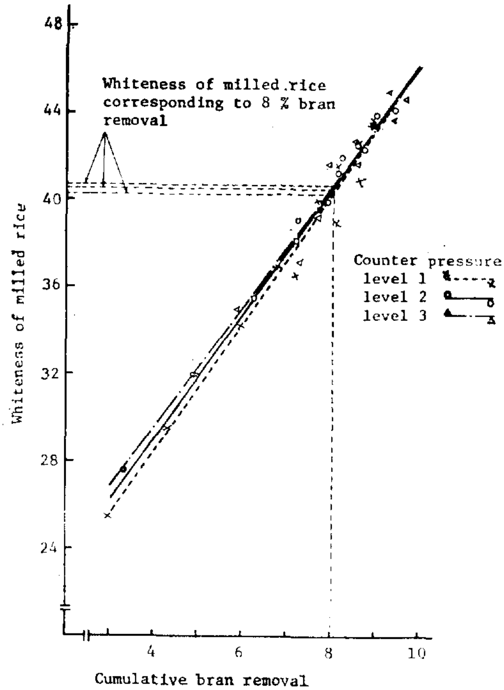



**Fig. 10. Relation betweeness of milled rice and cumulative bran remo**

sion equations were obtained.

$WM1 = 2.94\ CBR + 16.83\quad (r^2 = 0.976)$

$WM2 = 2.87\ CBR + 17.70\quad (r^2 = 0.994)$

$WM3 = 2.75 \cdot CBR + 18.66\quad (r^2 = 0.960)$

where WM; Whiteness of the milled rice at i level of counter pressure

CBR; Cumulative ban removal

## Ⅴ. Summary and Conclusions

As an attempt to investigate milling process in terms of the formation of various milling products, a series of experiments were conducted by varying the counter pressures in three selected levels. A fixed roller speed of a whitener with 850 rpm was used for this study. The paddy rice used for the test was the Milyang-23, one of the typical Tongil varieties. The formation of milled rice and by-products in each pass in the whitener were measured and analyzed subsequently for the bran removal, production of large and small broken kernels and head and milled rice recoveries when the whitening process was repeated.

The results of the study are summarized as follows:

1) The major portion of bran exceeding 75% of total bran was removed within the operation of 2nd pass. The bran removal rate was largely dependent on the counter pressure setting, giving the high removal rate at high pressure level.

2) The formation of large broken kernels was mainly achieved in the early stage of whitening process and the new breakge from the sound grain was deceased rapidly as the process repeated. The high counter pressure was greatly attributed to the production of the large broken kernels.

3) The small broken kernels collected in by-product collectors were generally small in amount relative to other components of whitening products, giving only less then 0.6% of the brown rice after the completion of 8% bran removal. The formation of the small broken kernels was not affected much on the levels of counter pressure tested.

4) Both the milled and head rice recoveries were influenced to some extent by the level of counter pressure. However, the high counter pressure setting was considered to be much objectionable because of its great attribution to lowering the head rice recoveries.

5) Whiteness meter readings were better correlated with the bran removal than with the other factors such as the number of passes. Thus, it can be confidently used as an index for a quick identification of whitening degree of the milled rice.

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