*Fluctuation of Physicochemical Properties of Rice at a Grain Elevator in Japan

Edenio Olivares Diaz [a], Shuso Kawamura [a,*], Atsushi Jo [a], Mizuki Kato [a], Shigenobu Koseki [a]

[a] Laboratory of Agricultural and Food Process Engineering, Graduate School of Agricultural Science, Hokkaido University, Sapporo, Hokkaido, Japan

* Corresponding author. Email: shuso@bpe.agr.hokudai.ac.jp

Abstract

Studies of the physicochemical properties of rice at harvesting time have shown that thicker kernels tend to be longer, wider, denser and heavier, and to have lower protein content than thinner ones. However, little information is available on variations in the physicochemical properties of rice after processing. The objective of this study was therefore to analyze the behavior of some physicochemical properties of brown rice of Japonica type during processing in a grain elevator. Physicochemical properties of rice were studied at different processing stages in a rice grain elevator. Samples were collected every five minutes for two hours at different stages, including after the huller, after the thickness grader and in the waste of the thickness grader, as well as after the color sorter and in the waste of the color sorter. Brown rice from the same batch of Japonica type variety Nanatsuboshi was used in this study. In general, results indicated that after being processed samples after the color sorter showed higher quality, while samples in the waste of thickness grader showed lower quality. Also, samples collected from the waste of the color sorter were found to have lower protein content, which is an unexpected result considering the lower weight and density of the kernel as well as the higher percentage of undesirable kernels, and could have been caused by the highly significant negative relationship between protein content and kernel thickness. Overall results indicated a possible correspondence relationship between physical and chemical properties.

Keywords: rice processing**,** rice physical properties, rice chemical properties, rice protein content, rice quality

1. Introduction

A rice grain elevator is an agricultural structure that processes and stores rice. In Japan, farmers transport the harvested rough rice to a grain elevator located in their region. The received batch of rough rice is weighed and dried until approximately 15% of moisture content to preserve its quality and is then stored in silos. At the same time, a volume of about 2 kg of rough rice from the received batch is taken and its quality is inspected automatically based on protein content, moisture content and the percentage of sound whole kernel of brown rice. The quality data is recorded in a computer and a copy is delivered to each farmer with a personal code, as detailed by Kawamura (2015). Later, before shipping to a milling factory, the rough rice stored in silos is hulled in a hulling system to remove the husk and the brown rice is then sorted in a thickness grader according to kernel thickness. Next, to improve the quality of the sample, a brown rice color sorter is used to remove undesirable kernels such as immature, damaged, discolored, dead, and broken kernels based on color information and to remove foreign materials such as stones, small pieces of plastic and glass based on differences in moisture content with rice kernel, as discussed by Kondo and Kawamura (2013).

As detailed above, information on physicochemical properties, such as the rate of sound whole kernel and level of protein content, is essential for classifying the quality of rice in Japan. Samples with higher percentages of sound whole kernel indicate higher quality due to the lower percentage of undesirable kernels and foreign materials, and in Japan brown rice sample with average moisture content of 15% is required to have more than 70% of sound whole kernel to be classified as high quality rice, as maintained by Mizuho National Foundation (2011). According to Hokkaido Agricultural Cooperative (Hokuren), in Hokkaido in northern Japan high quality sample of rice is required to comprise more than 80% sound whole kernel. Moreover, protein is an important constituent for determining the eating, processing and nutritional qualities of rice as well as the texture of cooked rice, as reported by Zhou et al. (2002) and Kawamura et al. (2014). Rice sample with lower percentage of protein content, which is sticky when cooked, is more palatable for both Japanese and East Asian people, as indicated by Kawamura et al. (1999).

The physicochemical properties of rice have been examined several times over the last decades. Results have indicated that fully matured kernels, which are contained in samples with higher percentages of sound whole kernel, tend to be longer, wider, thicker, denser and heavier than less matured kernels, which are mostly contained in samples with higher percentages of undesirable kernels, as revealed by Wadsworth et al. (1979) and Edenio et al. (2015). Also, Wadsworth et al. (1982) and Edenio et al. (2015) demonstrated that the number of undesirable kernels decreases as kernel thickness increases. This is caused by the fact that, at harvesting time, rice grain reaches its maximum length and width before it reaches its maximum thickness when the caryopsis is developing, as summarized by Kunze et al. (2004) and Bhattacharya (2011). In other words, among the three principal dimensions of the rice kernel, thickness is the slowest to develop. Therefore, at harvesting time, thicker kernels tend to be better-developed, to have had a longer growing period, and to be located mostly in the upper part of the rice panicle considering that grainfill happens from the top of the panicle downward, as revealed by Myers McClung (2004).

Hillerislambers et al. (1973) and Tanaka (2012) stated that, at harvesting time, high protein content was significantly correlated with light kernels, early heading, and short stature. Meanwhile, Matsue et al. (1992) stated that, at harvesting time, the percentage of protein content differs between kernels from the lower and upper part as well as between kernels located in primary and secondary rachis branches of the rice panicle. Also, Siebenmorgen et al. (2006) demonstrated that as kernel thickness within a sample increases, there is a decrease in protein content. These results were mostly due to the fact that glutelin, which is the major storage protein fraction in rice, decreases with the grainfill, as reported by Shih (2004), and as a result matured and thicker kernels tend to report lower protein content due to the longer growing period. Furthermore, Olivares Diaz et al. (2016) observed a correspondence but no causal relationship between thickness and protein content from the same batch of Japonica type of rice produced in Hokkaido, Japan after being processed by a color sorter.

As summarized above, various studies have been carried out on the physicochemical properties of rice mostly at harvesting time. However, there is little information on variations in the physicochemical properties of rice after processing. Thus, the objective of this study was to analyze the behavior of some physicochemical properties of brown rice from the same batch of Japonica type during processing in a grain elevator.

2. Materials and Methods

2.1. Rice sample

This study was conducted using brown rice from the same batch of Japonica type variety Nanatsuboshi, with average moisture content of approximately 15%, wet basis (w.b.), 135^{o}C, produced in Fukagawa, Hokkaido, Japan in 2014.

2.2. Rice sample collection

Samples were collected for two hours at different stages, such as after the huller, after the thickness grader and in the waste of the thickness grader, as well as after the color sorter and in the waste of the color sorter at the rice grain elevator at Fukagawa Mainary in Hokkaido, Japan (Figure 1).

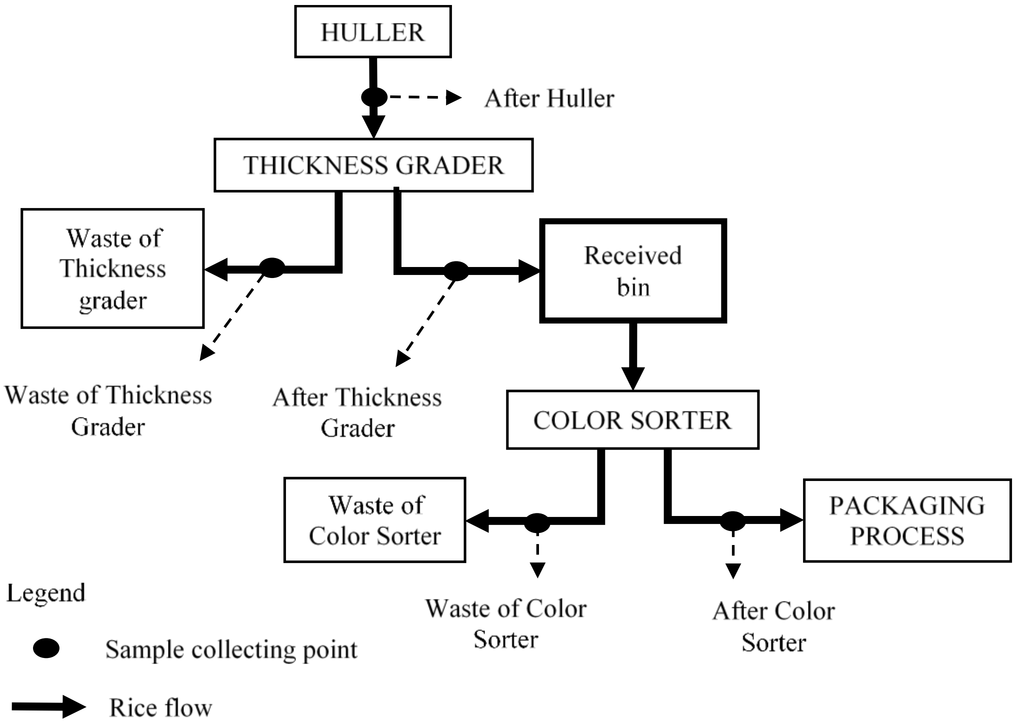

Figure 1. Flow chart of sample collection

Over the two hours, 15 samples were collected after the huller, after the thickness grader and in the waste of the thickness grader and 21 samples were collected after the color sorter and in the waste of the color sorter. The difference in the number of samples collected before and after the color sorter was due to the difference in the volume of rice processed in the huller and thickness grader (higher volume) and in color sorter machine (lower volume).

2.3. Devices and methods of measurement

2.3.1. Moisture content

Moisture content (*MC*) was determined by the oven method according to the JSAM (Japanese Society of Agricultural Machinery) standard method. About 10 g of whole grain rice was placed in a forced-air oven at 135°C for 24 hours and moisture was computed on a wet basis.

2.3.2. Component analysis

Components of brown rice were estimated from the number of kernels in each category using a visible light segregator (SATAKE, Hiroshima, Japan) and were expressed as a percentage of weight. Components of brown rice were divided according to the color information into the following categories, as suggested by Ohtsubo (1995) and the Japan Rice Millers Association (1997): sound whole, immature, broken, damaged, discolored and dead kernels.

2.3.3.Physical properties

Thousand-kernel weight (*TKW*) was determined by weighing 1,000 randomly drawn rough rice regular kernels in an electronic balance (Sartorious, Germany) and expressed in grams (g).

In the meantime, Bulk density (*BD)* was determined using a grain bulk-weight tester, Brauer type (Kiya, Saitama, Japan) and expressed as grams per liter (g/L). A volume of 150 g of each rice sample was inserted into the grain volume-weight tester. The volume measured (V_m) indicates the bulk density by the application of the Eq (1).

$$BD = \left(\frac{150}{V_m \cdot 1.5} \right) \cdot 1{,}000 \qquad (1)$$

Thickness distribution was measured with a sieve shaker. A volume of 100 grams was separated into 8 thickness categories at intervals of 0.1 mm, from less than 1.6 mm to more than 2.2 mm, which were expressed as a percentage of weight. The mean thickness (*MT*) of each sample was calculated by the application of Eq (2), and expressed in millimetres (mm).

$$MT = \frac{((2.25 \cdot WP_{o2.2}) + (2.15 \cdot WP_{2.1-2.2}) + (2.05 \cdot WP_{2.0-2.1}) + (1.95 \cdot WP_{1.9-2.0}) + (1.85 \cdot WP_{1.8-1.9}) + (1.75 \cdot WP_{1.7-1.8}) + (1.65 \cdot WP_{1.6-1.7}) + (1.55 \cdot WP_{B1.6})}{100} \qquad (2)$$

where *WP* is the weight percentage in each thickness fraction, the subscript $_{o2.2}$ represents kernels more than 2.2 mm thick, and the subscript $_{b1.6}$ represents kernels less than 1.6 mm thick.

2.3.4.Chemical properties

Crude protein content (*PC*) was determined using the Dumas method. The Dumas method involved the conversion of all nitrogen form in the sample to nitrogen oxides through combustion at high temperature, and subsequent measurement using a thermal conductivity detector. Results were given as %, which were converted into protein using conversion factor (5.95). Protein content was expressed in percentage of dry basis of brown rice (%, d.b., BR, Dumas).

3. Results and Discussion

3.1. Component analysis

Component analysis of the brown rice indicated that the percentage of sound whole kernel was highest in the samples collected after the color sorter. Meanwhile, undesirable kernel, such as immature, broken, damaged, discolored and dead kernel, was highest in samples collected in the waste of the thickness grader (Figure 2).

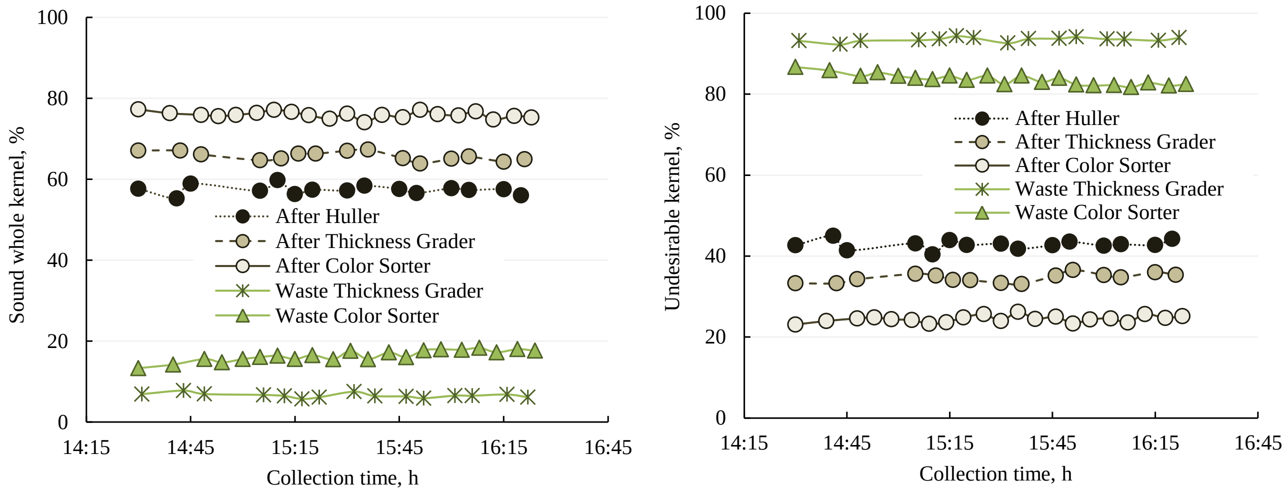

Figure 2. Component analysis of brown rice

These results were expected because the samples collected after the color sorter had been sorted by the thickness grader and by the brown rice color sorter machines, and therefore contained a higher percentage of sound whole kernel, indicating higher quality. On the other hand, samples in the waste of the thickness grader had been rejected after being processed by the thickness grader due to the higher percentage of undesirable kernels, indicating lower quality. The same results have been stated by Wadsworth et al. (1982) and Edenio et al. (2015). Moreover, these result confirm that higher percentages of sound whole kernel are usually found in samples with lower percentages of undesirable kernel not only at harvesting time but also after processing.

3.2. Physicochemical properties

Ranges of mean thickness, bulk density, kernel weight and protein content of each sample collected are summarized in Table 1.

Table 1. Range and mean of physicochemical properties of brown rice

Process	Mean thickness, mm			Bulk density, g/L			Thousand-kernel weight, g			Protein content, %, d.b., BR, Dumas		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
After Huller	2.12	2.14	2.13	856	862	859	21.3	21.8	21.5	7.5	7.8	7.7
After Thickness Grader	2.14	2.17	2.16	866	871	869	22.6	22.9	22.7	7.5	7.7	7.6
Waste Thickness Grader	1.87	1.89	1.88	778	784	781	13.8	14.5	14.1	7.9	8.2	8.1
After Color Sorter	2.16	2.18	2.17	860	867	864	23.0	23.2	23.1	7.5	7.7	7.6
Waste Color Sorter	2.14	2.15	2.14	841	846	843	20.7	21.3	21.0	7.2	7.4	7.3

One-way analysis of variance (ANOVA) and Tukey-Kramer's test reported with 99% of confidence significant differences in mean thickness, mean bulk density and mean kernel weight among the samples collected. Moreover, one-way ANOVA and Tukey-Kramer's test indicated with 99% of confidence significant differences in mean protein content between samples collected after the huller, after the thickness grader and after the color sorter on the one hand, and samples collected in the waste of thickness grader and color sorter on the other (Figure 3).

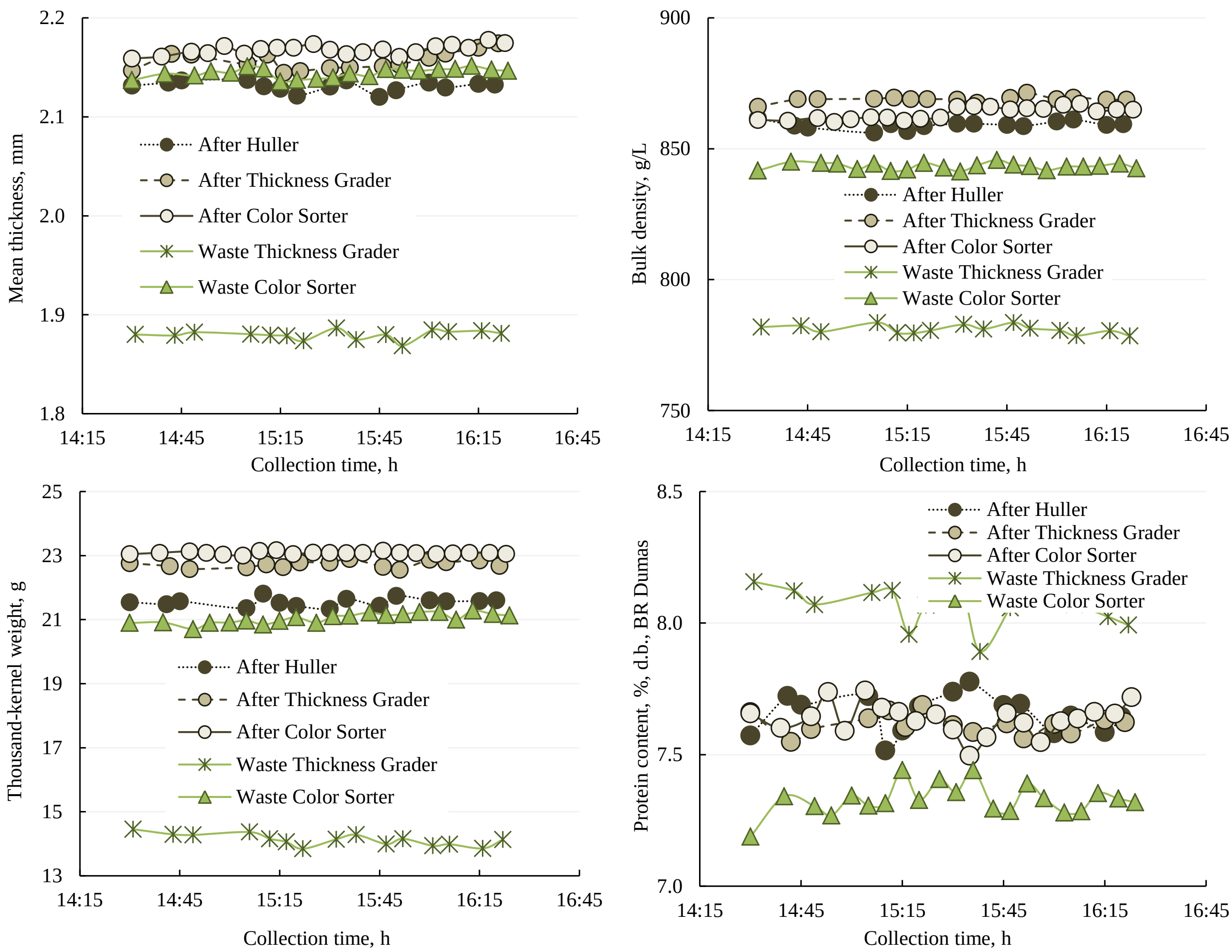

Figure 3. Behavior of physicochemical properties of brown rice

Measurements of physical properties such as component analysis, mean thickness, bulk density and kernel thickness also reported expected results. In general, samples with higher percentages of sound whole kernel (after the thickness grader and after the color sorter), which were mostly composed of matured kernels, were found to have thicker, heavier and denser kernels, and therefore tended to have higher quality than the less matured kernels which were more found in the rejected sample (waste of thickness grader). The same result was reported by Kunze et al. (2004) and Bhattacharya (2011). This result revealed that, due to the longer growing period as well as the fact that grainfill happens from the top of the panicle downward, the more matured, thicker kernels tended to be heavier and denser not only at harvesting time but also after being processed.

On the other hand, samples collected from the waste of the color sorter showed the lowest protein content, which is an unexpected result considering the lower weight and density of the kernels as well as the higher percentage of undesirable kernel. Previous studies have reported that samples with higher percentages of undesirable kernel, which tend to contain thinner, lighter and less dense kernels, tend to have higher percentages of protein, as maintained by (Hillerislambers et al. 1973; Matsue et al. 1992; Siebenmorgen et al. 2006). This could be because samples with higher protein content tend to have a higher fraction of glutelin, which decreases with the grainfill, as reported by Shih (2004).

This unexpected behavior could be related to the results for kernel thickness: mean thickness in samples collected in the waste of the color sorter was found to be similar to that in samples taken after the huller, after the thickness grader, and after the color sorter (Figure 3). This suggested a detailed study of differences in physicochemical properties by thickness fraction.

3.2.1.Physicochemical properties by thickness fraction

Sample preparation

A volume of approximately 100 g was taken from each subsample (samples collected at fixed intervals at a collecting point). All subsamples collected from the same collecting point were joined to create a new sample called raw material. The new sample (raw material) was divided into various thickness fractions using a laboratory thickness grader (SATAKE, Japan). The sample from the waste of the thickness grader was divided into two thickness fractions (below 1.9 mm and over 1.9 mm), and the rest of the samples were divided into three thickness fractions (below 2.1 mm, between 2.1 and 2.2 mm, and over 2.2 mm). Next, the physicochemical properties were analyzed as explained above.

Results and discussion

Component analysis reported that the percentage of sound whole kernel increased with increases in thickness fraction within each variety, the same result that was achieved by Wadsworth et al. (1982) and Edenio et al. (2015). Moreover, samples after the color sorter indicated the highest percentage of sound whole kernel and the lowest percentage of undesirable kernel among the samples analyzed. These were expected results considering that the highest thickness fraction was mostly composed of matured kernels and that samples after the color sorter were collected after being sorted twice, and therefore had the highest quality among the samples analyzed (Figure 4).

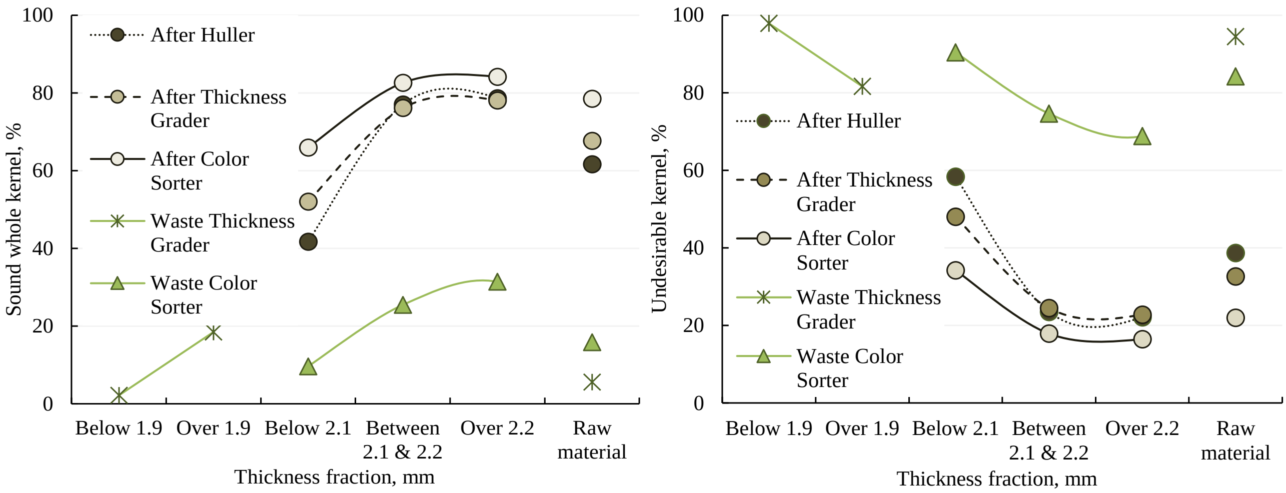

Figure 4. Component analysis of brown rice by thickness fraction

Expected results were obtained for properties such as bulk density and kernel weight. Samples collected after the color sorter had the highest bulk density and kernel weight among the samples analyzed. Also, mixed ANOVA reported significant differences in mean bulk density and thousand-kernel weight between the rejected samples (waste of the thickness grader and waste of the color sorter) and the rest of the samples analyzed. This could be related to the higher percentage of sound whole kernel. In addition, kernel density, weight and thickness increased as thickness increased. Furthermore, Mixed ANOVA recognized significant differences in mean kernel density, weight and thickness between samples in the lowest and highest thickness fractions within each variety. The same result was reported by Wadsworth et al. (1979) and Edenio et al. (2015). This result could be related to the higher percentage of sound whole kernel contained in the highest thickness fraction considering that these kernels were more mature due to the longer growing period. Moreover, Mixed ANOVA reported no significant differences in the mean of mean thickness among the samples, which is an unexpected result considering the higher percentage of undesirable kernels in samples from the waste of the color sorter (Figure 5).

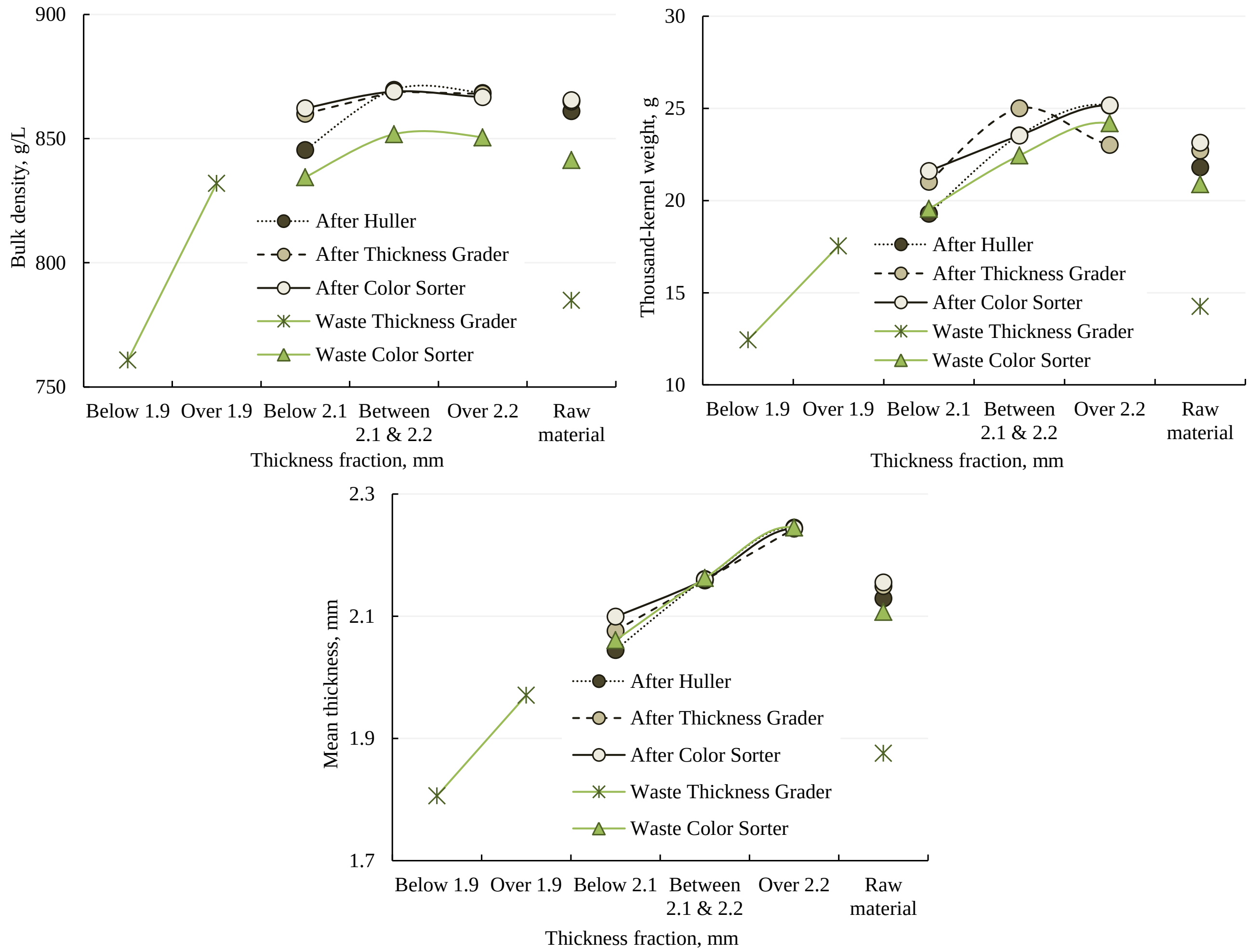

Figure 5. Behavior of kernel density, weight and thickness of brown rice by thickness fraction

Secondly, results for protein content indicated that the protein content within each sample decreased as thickness increased. The same result was reached by Siebenmorgen et al. (2006). Meanwhile, Mixed ANOVA reported significant differences in mean protein content mostly between the rejected samples (waste of the thickness grader and waste of the color sorter) and the rest of the samples analyzed (Figure 6).

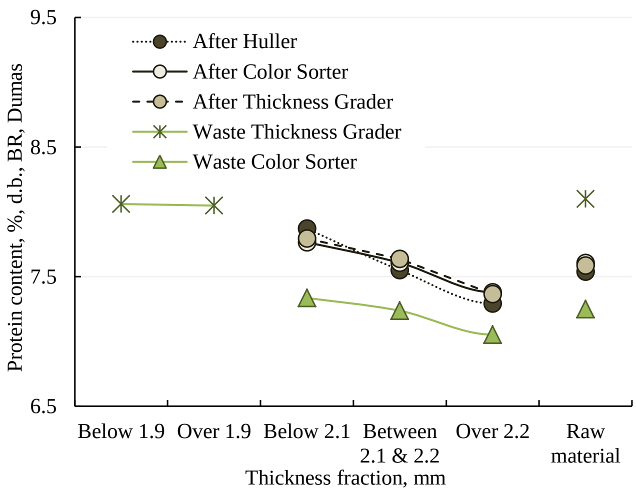

Figure 6. Behavior of protein content of brown rice by thickness fraction

Results for protein content also reported an unexpected behavior. Samples from the waste of the color sorter had the lowest protein content among the samples analyzed, which is an unexpected result considering that high protein content is significantly correlated with light kernels, as stated by Hillerislambers et al. (1973) and Tanaka (2012), and that component analysis of samples with higher percentages of undesirable kernel revealed that they contained lighter kernels.

The unexpected result for protein content could possibly be explained by the result for kernel thickness by thickness fraction. The samples from the waste of the color sorter indicated no significant differences with samples after the huller, after the thickness grader, and after the color sorter at any thickness fraction, which indicated that the samples from the waste of the color sorter were also composed of thicker kernels. Linear regression indicated highly significant negative regression of mean protein content on mean thickness (Figure 7).

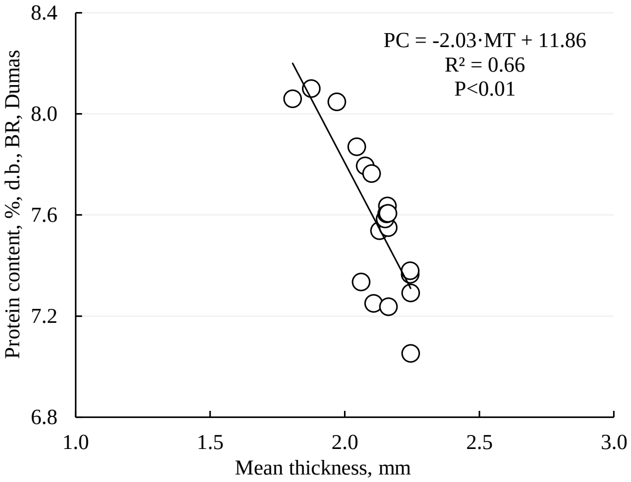

Figure 7. Relationship between protein content and mean thickness of brown rice by thickness fraction

Moreover, even though samples in the waste of the color sorter had previously reported a lower percentage of sound whole kernels, the component analysis indicated that these samples were mostly comprised of sound whole and immature kernel (Figure 8).

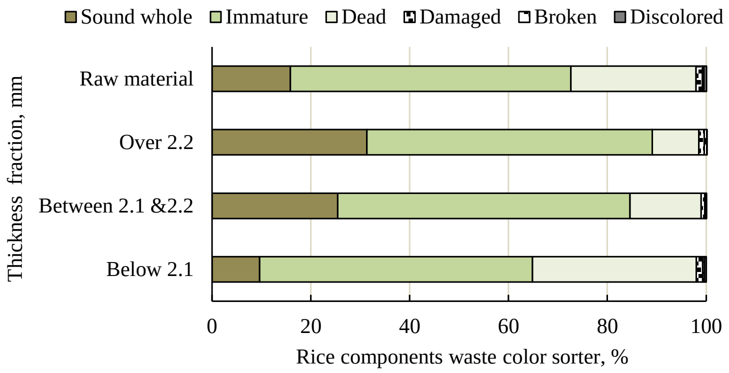

Figure 8. Component of brown rice in the waste of the color sorter by thickness fraction

This result revealed that those kernels previously classified as immature based on color information tended to also be thicker or closer to the thickness reported for kernels contained within the percentage of sound whole kernel. Also, this result showed that protein content was more associated with thickness than with classifications based on color information, such as matured, immature, dead, discolored, etc.

In general, these results indicated that protein content is not only significantly negatively correlated to kernel weight at harvesting time, as previously reported by Hillerislambers et al. (1973) and Tanaka (2012), but that it could also be highly significantly negatively correlated with kernel thickness after being processed. This behavior could be caused by the longer growing period as well as the fact that grainfill happens from the top of the panicle downward. Because thickness is the last dimension to reach its maximum level when the rice kernel is developing, the thicker kernels tended to be exposed to a longer growing period, and therefore also tended to be denser, heavier and located in the upper part of the rice panicle. Also, because of the longer growing period, those thicker kernels reported lower protein content considering that glutelin decreases with the grainfill.

Additionally, this result reaffirmed a correspondence but no causal relationship between physical (kernel thickness and weight) and chemical (protein content) properties of brown rice Japonica type from the same batch after being processed, as was observed by Olivares Diaz et al. (2016).

4. Conclusions

From the results achieved in this research, it can be concluded that samples after the color sorter contained thicker, heavier and denser kernels, as well as higher percentages of sound whole kernel and lower percentages of immature kernel, and thus had the highest quality among the samples analyzed in the study. On the other hand, samples from the waste of the thickness grader contained thinner, lighter and less dense kernels, and were of lower quality considering the higher percentage of undesirable kernel.

Furthermore, after being processed, the protein content of brown rice of Japonica type from the same batch reported a highly significant negative relationship with kernel thickness. This relationship could have caused the lower protein content in samples from the waste of the color sorter, which was an unexpected behavior.

In addition, a possible correspondence relationship was detected between physical and chemical properties of brown rice Japonica type from the same batch after being processed in a grain elevator, which could have been caused by the longer growing period of the kernels during their development as well as the fact that grainfill happens from the top of the panicle downward.

References

Bhattacharya, K. R., 2011. *Rice Quality*. Cambridge, UK: Woodhead Publishing Limited. 563 p.

Edenio, O.D., S. Kawamura, and S. Koseki, 2015. Physical properties of rough and brown rice of Japonica, Indica and NERICA types. CIGR Journal, (Special issue: 18th World Congress of CIGR), 274–285. Open access at http://www.cigrjournal.org

Hillerislambers, D., J.N. Rutger, C.O. Qualset, and W.J. Wiser, 1973. Genetic and environmental variation in protein content of rice (Oryza sativa L.). Euphytica, 22(2), 264–273. http://dx.doi.org/10.1007/BF00022634

Japan Rice Millers Association, 1997. *Rice Museum. Text of Quality Evaluation of Rice (in Japanese)*. Japan: Japan Rice Millers Association and Kett Electric Laboratory.60 p.

Kawamura, S., 2015. Agro-food processing engineering. In *Frontier of Agricultural Sciencies Research Faculty of Agriculture Hokkaido University*. Kyoto, Japan: Shoukadoh Book Sellers. Eds., T. Nakatani, Y. Hashidoko, Y. Uchida, J. Kashiwagi, T. Yamada, H. Shimura, S. Koike, T. Hira and S. Koseki. 184–197.

Kawamura, S., S. Fujikawa and H. Iino, 2014. Determination of rice amylose content at grain elevator by combined use of near-infrared spectrometer and a visible light segregator. In *7th International Symposium on Machinery and Mechatronics for Agricultural and Biosystems Engineering (ISMAB)*. Yilan, Taiwan, May 21-23. 485–490.

Kawamura, S., M. Natsuga, and K. Itoh, 1999. Determination of undried rough rice constituent content using near-infrared transmission spectroscopy. Transactions of the ASAE 42(3), 813–818. http://dx.doi.org/10.13031/2013.13246

Kondo, N., and S. Kawamura, 2013. Postharvest automation. In *Agricultural Automation*. Boca Raton, Florida, USA: CRC Press Taylor & Francis Group. Eds., Q. Zhang and F. Pierce. 367–383.

Kunze, R., L. Yubin and T. Wratten, 2004. Physical and mechanical properties of rice. In *RICE: Chemistry and Technology*. 3rd Edition. St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc. Ed., .E.T. Champagne. 191–221.

Matsue, Y., Odahara, K., Hiramatsu, M., and Furuno, K. 1992. Protein and amylose content of milled rice at individual rachis-branches differing in the position on a rachis (in Japanese). A Report of the Kyushu Branch of the Crop Science Society of Japan 59, Kyushu, Japan. 43–44.

Mizuho National Foundation for Food Inspection, 2011. *Agricultural Products Inspection Notebook (in Japanese)*. Tokyo, Japan. 210 p.

Myers McClung, A., 2004. The rice plant: growth, development, and genetic improvement. In *RICE: Chemistry and Technology*. 3rd Edition. St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc. Ed., .E.T. Champagne. 25-48.

Ohtsubo, K., 1995. Physical properties and measurement thereof. In *Rice Post-Harvest Technology*. Tokyo, Japan: The Food Agency, Ministry of Agriculture, Forestry and Fishering, Japan. Ed., A. Hosokawa. 443–450.

Olivares Diaz, E., S. Kawamura, A. Jo and S. Koseki, 2016. Relationship between rice kernel maturity and physicochemical properties. In *8th International Symposium on Machinery and Mechatronics for Agricultural and Biosystems Engineering (ISMAB)*. Niigata, Japan, May 23-25. 347–352.

Shih, F., 2004. Rice proteins. In *RICE: Chemistry and Technology*. 3rd Edition. St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc. Ed., .E.T. Champagne. 143-162.

Siebenmorgen, T.J., R.C. Bautista and J.F. Meullenet, 2006. Predicting rice physicochemical properties using thickness fraction properties. Cereal Chemistry, 83(3), 275–283. http://dx.doi.org/10.1094/CC-83-0275

Tanaka, S., 2012. Seed protein of rice and possibilities of its improvement through mutant genes. In *Seed Proteins: Biochemistry, Genetics, Nutritive Value*. The Hague, The Netherlands: Martinus Nijhoff/Dr W. Junk Publishers. Eds.W. Gottschalk and H.F. Muller. 225–245.

Wadsworth, J., J. Matthew and J. Spadaro, 1982. Milling performance and quality characteristics of Starbonnet variety rice fractionated by rough rice kernel thickness. Cereal Chemistry, 59(1), 50–54.

Wadsworth, J., J. Matthew and J. Spadaro, 1979. Physical and physicochemical properties of starbonnet variety rice fractionated by rough rice kernel thickness. Cereal Chemists, 56(6), 499–505.

Zhou, Z., K. Robards, S Helliwell and C. Blanchard, 2002. Composition and functional properties of rice. International Journal of Food Science and Technology, 37(8), 849–868. http://dx.doi.org/10.1046/j.1365-2621.2002.00625.x