JARQ 47 (2), 141 – 151 (2013) http://www.jircas.affrc.go.jp

REVIEW

Development of Classification Drying of High Moisture Wheat Grain According to the Moisture Content

Genta KANAI*, Katsuhiko TAMAKI[1] and Yuji NAGASAKI[2]

Agro-Production Technologies and Management Research Division, NARO Tohoku Agricultural Research Center, National Agriculture and Food Organization (NARO) (Morioka, Iwate 020–0198, Japan)

Abstract

A new method of drying early harvested wheat grains having high moisture content has been developed: classification drying based on moisture content using a thickness grader. Grain size is known to be roughly proportional to moisture content. We therefore clarified the relation between grain thickness and moisture content before the drying process, and demonstrated the possibility of new classification drying. Based on the results, we found that a 3.2-mm sieve was optimal for a roughly uniform separation of grains having moisture content of around 35%. For the drying process, the thicker grain group had higher moisture content and its flour was vulnerable to discoloration and degraded starch quality. Moreover, we found that it is important leave grains of high moisture content—the thicker grain group in classification drying—exposed to airflow in order to prevent degraded quality. Practical experiments conducted with a circulating batch dryer showed that the thinner grain group having lower moisture needs less time for drying due to the lower initial moisture content.

Discipline: Postharvest technology
Additional key words: ash content, flour quality, protein content, starch quality, thickness

Introduction

1. Wheat production in Japan

In the Japanese market, consumers demand high quality grain products. However, it is difficult to produce high quality wheat grains in Japan, given the very severe circumstances of production where the wheat harvesting season (in June) also coincides with Japan's rainy season (except in Hokkaido). We therefore engaged in a series of research and development activities to advance both the harvesting and drying processes as adapted to high moisture wheat grain. The results of those R&D efforts have already been published in Japanese[1,2,3,4,5,6]. This paper reviews our current work, where we focus on the classification drying of high moisture wheat grain.

2. Harvesting process

(1) Introduction

Before developing the drying process, we examined the damage to wheat grain in the harvesting process. Methods of reducing grain degradation resulting from the harvesting process were examined by using popular types of harvesters (e.g., head-feeding and ordinary-type combines). A common wheat cultivar (*Norin-61*) was cultivated normally in Ibaraki prefecture, Japan. The color of flour was measured using a spectral diffraction colorimeter (CM3500; Konica Minolta Holdings).

(2) Head-feeding combines[1]

Harvesting tests were conducted on wheat grains having high moisture content (30–45%). Experiments demonstrated that grains having moisture content of 45% could be harvested with no machine trouble, achieving a chaff rate less than about 5% at the grain outlet, total

Present address:
[1] NARO Agricultural Research Center, NARO (Tsukuba, Ibaraki 305–8666, Japan)
[2] Shikoku Research Center, NARO Western Region Agricultural Research Center, NARO (Zentsuuji, Kagawa 765–8508, Japan)
*Corresponding author: e-mail kanaigen@affrc.go.jp
Received 5 March 2012; accepted 2 July 2012.

grain loss less than about 2%, and damaged grain less than about 1%. Harvesting grains having moisture content of around 40% with rapid drying can provide better quality than harvesting grains having a lower moisture content after rainfall. Harvesting with the threshing cylinder operating at low-speed rotation and at normal operational speed improved the color of flour. The color differential in comparison to that harvested by using a binder was less than 0.6.

(3) Ordinary-type combines[2]

Harvesting tests were also conducted on wheat grains having high moisture content (18–47%). The harvesting of grains having moisture content less than 40% was demonstrated as being preferable in terms of grain quality, harvesting precision, and ease of drying. From a mechanical perspective, however, grains having moisture content of 45% could also be harvested without difficulty. The total grain loss through all experiments was less than 3%. The damaged grain rate was around 5% or less for grains having moisture content higher than 45%, and less than 1% for grains having moisture content less than 40%.

Harvesting with the threshing cylinder operating at low-speed rotation and at normal operational speed improved the color of flour, especially for wheat having moisture content higher than 45%.

(4) Harvesting and the subsequent process

Based on our results and recent combine developments, farmers can harvest grains having high moisture content of about 40%, but the subsequent process of drying must be adapted accordingly. Even if farmers had to harvest enough dried grains, they would still want to harvest early as they need to seed the next crops at the best timing after harvest.

Development of classification drying

1. Background

In wheat production, the drying process is crucial for wheat quality. Wheat matures and dries unevenly, even within a single field. It is impossible for an elevator to gather grains having the same moisture content because each batch of grain from the fields has a different moisture content. Wheat after drying tends to exhibit a nonuniform quality due to its heterogeneous initial conditions.

Japanese wheat production thus faces a serious predicament. Unfortunately, the wheat harvesting season (in June) also coincides with the rainy season in most parts of Japan. Although farmers must harvest a sufficient amount of wheat dried to a moisture content of less than 27% in order to avoid rain damage, many farmers harvest wheat before it is sufficiently dried. Such early harvested wheat grains having high moisture content tend to degrade, especially in terms of starch quality, due to delayed drying. Japanese wheat is mainly consumed in the form of *Udon* noodles. The starch quality directly affects the taste and texture of noodles. Therefore, the drying process must be improved not only to alleviate uneven drying but also to dry wheat grains of high moisture content.

2. Concept of classification drying

A new method of classifying early harvested wheat grains having high moisture has been developed: classification drying based on moisture content using a thickness grader. Grain size is known to be roughly proportional to moisture content. Based on that fact, this method classifies grains into groups by thickness. Grains are thus classified according to their moisture content. The moisture content distribution curves are narrower for these classified groups. Each group is dried under appropriate conditions based on moisture content. This method enables more uniform initial moisture content for each drier and more uniform quality after drying than a conventional method. Figure 1 illustrates the concept of classification drying.

3. Relation between grain thickness and moisture content[3]

(1) Introduction

Here we specifically elucidate the relation between grain thickness and moisture content, and thereby establish the best grading thickness, moisture content distribution of each thickness group, and consequential thickness distribution of grains examined before and after drying. A rotary grader was also used to conduct practical grading tests.

(2) Changes in thickness distribution

Table 1 shows the thickness distribution of grains before and after drying. Table 2 shows the change in thickness class after drying for the same samples as listed in Table 1. Samples were harvested 50 to 58 days after heading, with moisture content ranging from 43.1% to 16.9%. The thickness distribution before drying shows that grains harvested early are thicker than those harvested later. Drying in the field apparently reduced grain thickness at harvesting. The thickness distribution after drying shows that grains harvested later are thicker than those harvested early. Maturation in the field apparently results in increased grain thickness after drying. As shown in Table 2, the grains harvested earlier dropped down in more classes of thickness than grains harvested later. The grains harvested earlier have higher moisture content and shrink while drying. In terms of pre-dried grain thickness, grains harvested later become thinner while drying in the field. However, such grains are actually thicker as a result of relative maturation after drying.

Figure 2 shows three typical patterns of change in the moisture content distribution of wheat. At the early high moisture stage, a peak in the distribution appears higher than the average moisture content. At the intermediate stage, two higher and lower peaks appear. The higher peak consists of larger grain groups (mainly the 3.2 to 3.6-mm group); the lower peak consists of smaller grain groups (mainly the 2.8 to 3.2-mm group). At the sufficiently late drying stage, a peak appears for the lower group. The group of larger grains was observed to have higher moisture content at every stage.

(3) Best classification thickness

Figure 3 shows the average moisture content and changes of the six classified groups. The larger grain group has higher moisture content and showed a clear tendency toward higher moisture content. The effective sieve size estimated for the two-group classification drying method was around 3.2 mm, given the larger difference in average moisture content between the 2.8 to 3.2-mm group and 3.2 to 3.6-mm group than that between any other adjacent groups.

The best sieve size for separating wheat grains having high moisture was found to be around 3.2 mm, as based on observations of both grain thickness and moisture content. The resultant two groups have higher and lower moisture content, respectively. Figure 4 shows the results of tests using a rotary grader with 3.0-mm, 3.2-mm, and 3.4-mm sieves. For the 3.0-mm sieve, (a) in Fig. 4 shows a maximum difference of 6% between the thicker and thinner grains with initial moisture content of 37%. More than 50% of the grains was classified as being thicker with initial moisture content of 25-45%. For the 3.2-mm sieve, (b) in Fig. 4 shows a maximum difference of 5% between over and under the sieve, with initial moisture content of 30%. The thicker and thinner grains were almost equal in amount, with initial moisture content of 35%. For the 3.4-mm sieve, (c) in Fig. 4 shows a maximum difference of 8% between over and under the sieve, with initial moisture content of 25%. More than 70% of the grains was classified as being thinner with initial moisture content of 15-40%. From the results the 3.2-mm sieve is best suited for roughly separating grains uniformly at moisture content of around 35%.

4. Effect of thickness classification on ash content and protein content[6]

Figure 5 shows the results of thickness classification; Figure 6 shows the ash content and protein content of flour obtained from the same samples. From the results, the ash content and protein content of samples for

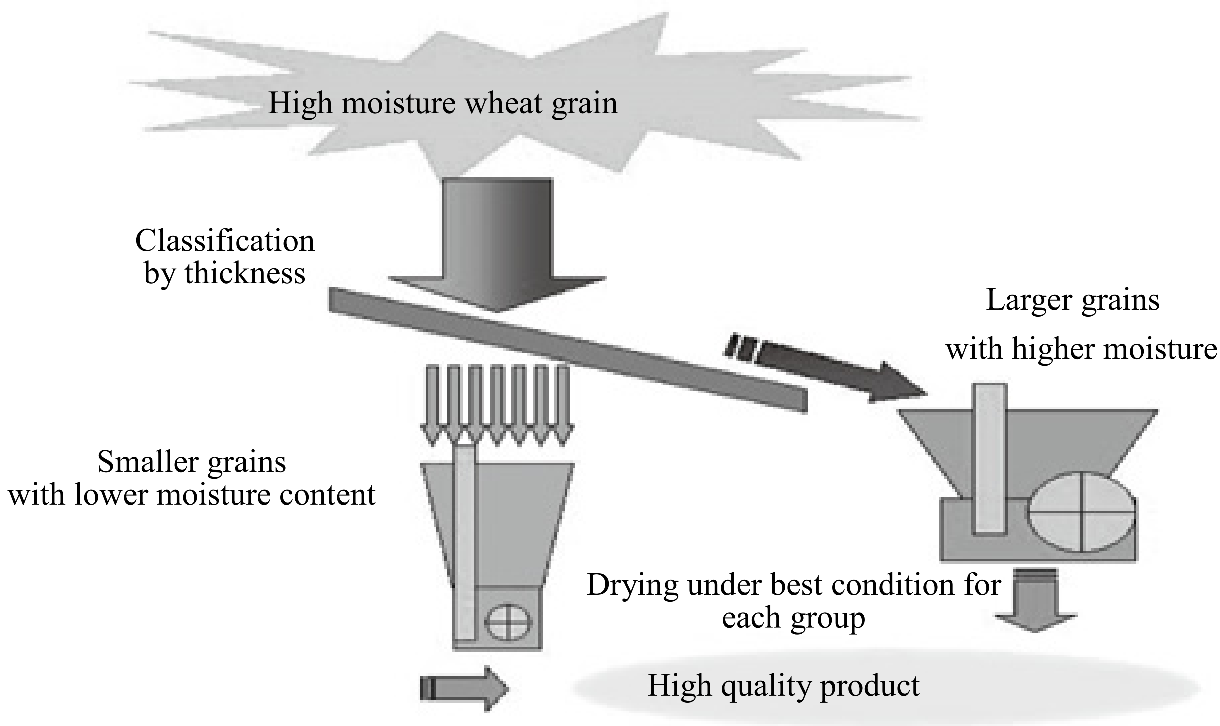


Fig. 1. The concept of classification drying

Table 1. Thickness distribution of grains before and after drying*

	Thickness distribution before drying		Thickness distribution after drying (%)				
	Class of thickness (mm)	(%)	0-2.0	2.0-2.4	2.4-2.8	2.8-3.2	(mm)
50 days after heading	0-2.0	0.2	0.2	0.0	0.0	0.0	
(8 June 2004)	2.0-2.4	1.1	0.8	0.3	0.0	0.0	
Moisture Content (MC):	2.4-2.8	9.2	1.1	7.5	0.6	0.0	
43.10%	2.8-3.2	40.9	0.8	19.3	20.8	0.0	
	3.2-3.6	39.5	0.2	7.3	28.7	3.3	
	3.6-4.0	6.7	0.1	1.0	4.7	0.9	
	4.0-	2.5	0.0	0.3	1.9	0.2	
	Total	100.0	3.1	35.8	56.7	4.4	(%)
53 days after heading	0-2.0	0.2	0.2	0.0	0.0	0.0	
(11 June 2004)	2.0-2.4	2.7	1.3	1.4	0.0	0.0	
MC: 40.2%	2.4-2.8	14.7	0.4	12.2	2.1	0.0	
	2.8-3.2	58.8	0.3	13.1	43.7	1.6	
	3.2-3.6	18.1	0.0	2.0	14.3	1.8	
	3.6-4.0	4.6	0.0	0.6	3.2	0.8	
	4.0-	0.9	0.0	0.1	0.7	0.1	
	Total	100.0	2.4	29.3	64.0	4.3	(%)
56 days after heading	0-2.0	0.3	0.3	0.0	0.0	0.0	
(14 June 2004)	2.0-2.4	3.7	0.9	2.8	0.0	0.0	
MC: 33.2%	2.4-2.8	17.4	0.2	11.3	5.9	0.0	
	2.8-3.2	66.5	0.2	7.7	50.8	7.8	
	3.2-3.6	9.4	0.0	0.6	5.9	2.8	
	3.6-4.0	2.5	0.0	0.1	1.4	1.0	
	4.0-	0.2	0.0	0.0	0.1	0.1	
	Total	100.0	1.7	22.5	64.1	11.7	(%)
57 days after heading	0-2.0	0.7	0.7	0.0	0.0	0.0	
(15 June 2004)	2.0-2.4	7.3	0.9	6.4	0.0	0.0	
MC: 24.8%	2.4-2.8	29.2	0.1	10.5	18.5	0.0	
	2.8-3.2	57.4	0.1	4.1	41.5	11.7	
	3.2-3.6	4.6	0.0	0.2	1.1	3.4	
	3.6-4.0	0.7	0.0	0.0	0.4	0.3	
	4.0-	0.0	0.0	0.0	0.0	0.0	
	Total	100.0	1.9	21.2	61.4	15.4	(%)
58 days after heading	0-2.0	0.9	0.9	0.0	0.0	0.0	
(16 June 2004)	2.0-2.4	13.2	0.4	12.7	0.1	0.0	
MC: 16.9%w.b.	2.4-2.8	54.4	0.0	4.9	49.5	0.0	
	2.8-3.2	30.5	0.0	0.4	18.8	11.3	
	3.2-3.6	0.9	0.0	0.1	0.5	0.4	
	3.6-4.0	0.0	0.0	0.0	0.0	0.0	
	4.0-	0.0	0.0	0.0	0.0	0.0	
	Total	100.0	1.3	18.1	68.8	11.8	(%)

* 1. Wheat samples (*Norin-61*) were ordinary cultivated in Ibaraki prefecture, Japan.
2. Moisture content is indicated on a wet basis.
3. Drying: less than 12.0%
4. Initial moisture content was measured using 10-g grains at 135°C for 24 hours.
5. The moisture content of each kernel was measured using a single kernel moisture meter (CTR800E, *Shizuoka Seiki*).
6. On each harvesting day, 7-10 kg of samples were collected from well-mixed grain discharged by the combine harvester.
7. Classifications were made using a sieve (standard model of the Japanese Food Agency).
8. Each ratio is based on the number of grains.

Table 2. Change in thickness class after drying

	Days after heading					
	50	53	56	57	58	
Same class	1.1	5.4	16.7	37.4	74.5	(%)
1 class (0.4 mm) down	32.3	59.0	65.9	56.3	24.5	(%)
2 classes (0.8 mm) down	50.0	28.6	14.9	5.5	0.9	(%)
3 classes (1.2 mm) down	13.0	5.6	2.2	0.7	0.1	(%)
4 classes (1.6 mm) down	3.1	1.3	0.3	0.0	0.0	(%)
5 classes (2.0 mm) down	0.4	0.1	0.0	0.0	0.0	(%)

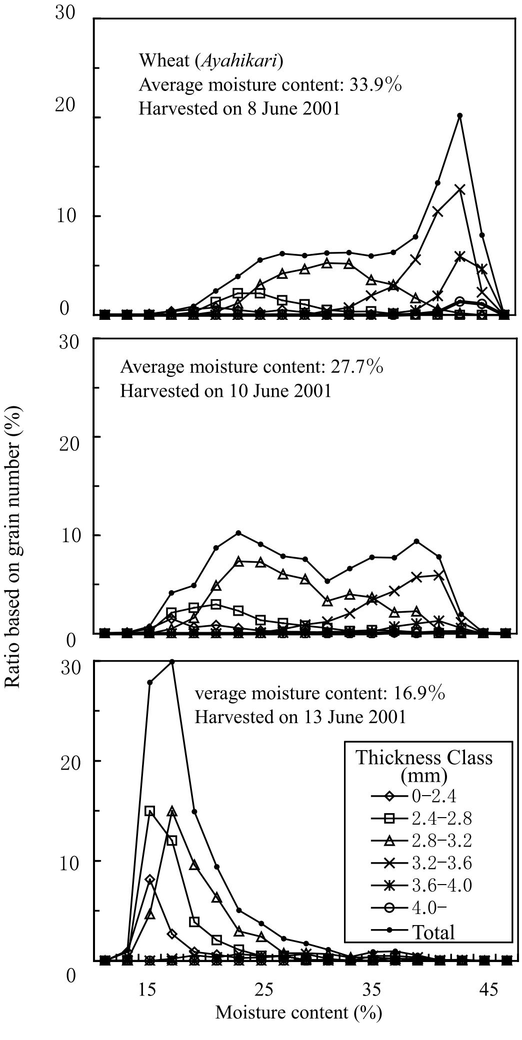


Fig. 2. Changes in distribution of moisture content for each thickness class*

*1. Average moisture content was measured using 10 g of grain heated at 135°C for 24 hours.
2. The moisture content of each kernel was measured using a single kernel moisture meter (CTR800E, Shizuoka Seiki).
3. Samples of each harvesting day were 7-10 kg collected from the well mixed grain discharged by the combine harvester.
4. Classification was made with the sieve (standard model of the Japanese Food Agency).

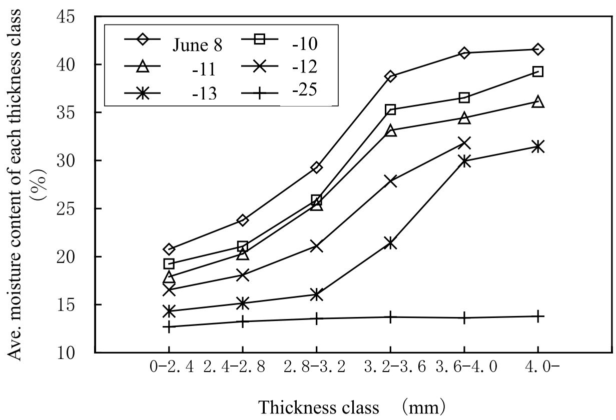


Fig. 3. Average moisture content and changes of the six classified groups

*1. Wheat: *Ayahikari*, harvested in 2001
2. The moisture content of each kernel was measured using a single kernel moisture meter (CTR800E, Shizuoka Seiki).
3. Samples of each harvesting day were 7-10 kg collected from the well mixed grain discharged by the combine harvester.
4. Classification was made with the sieve (standard model of the Japanese Food Agency).

over the sieve were higher than those for under the sieve.

5. Effects of drying conditions on classified grain[4]

(1) Introduction

We examined the effects of drying conditions on classified grains in order to determine how to avoid the degradation of wheat quality with classification drying. The airflow and drying temperature was examined as drying conditions. The thin layer drying was as ideal drying condition. No airflow was intended to simulate a condition of drying trouble. In the circulating dryer, high moisture grain may cause bridge trouble in the tempering tank, possibly subjecting it to high temperature with poor airflow conditions.

The effects of drying conditions on grain quality were evaluated based on the color of flour and starch quality.

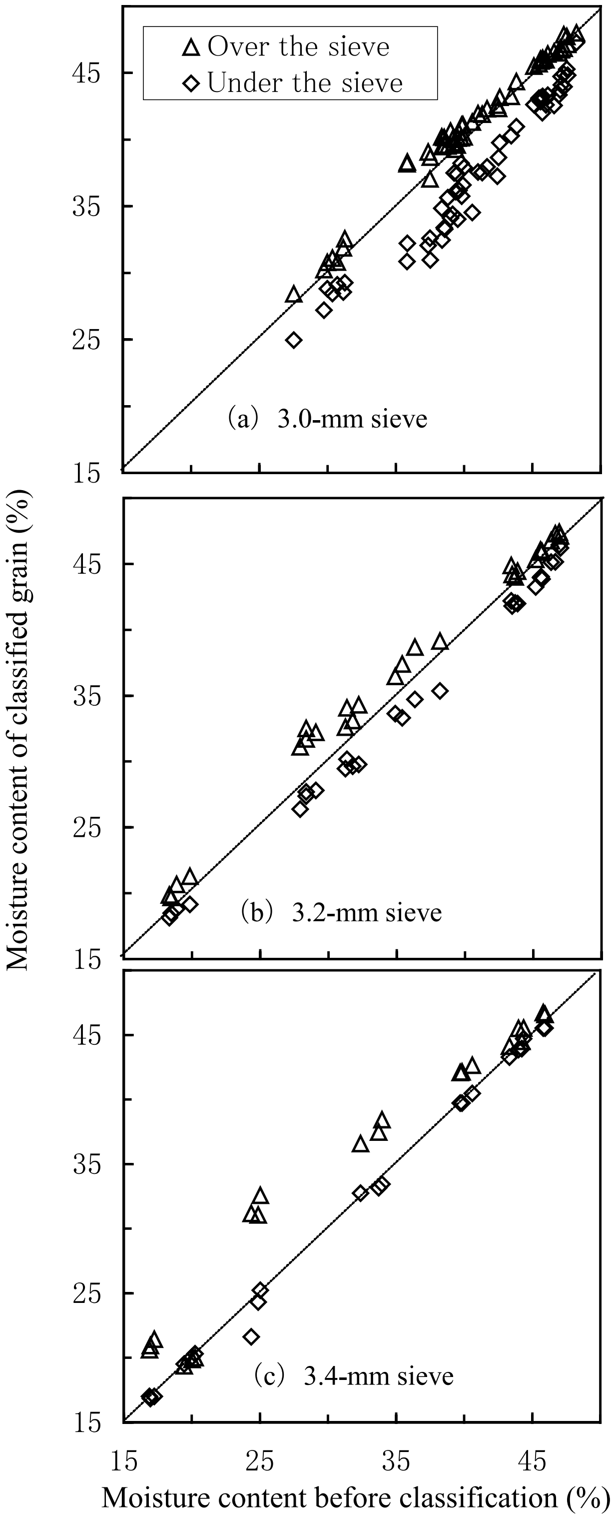


Fig. 4. Moisture content of grain before and after classification*

*1. Moisture content was measured using 10 g of grain heated at 135°C for 24 hours.
2. Samples of each harvesting day were 5-10 kg collected from the well mixed grain discharged by the combine harvester.
3. Classification was made using the rotary thickness grader (A-33, Tiger Kawashima).

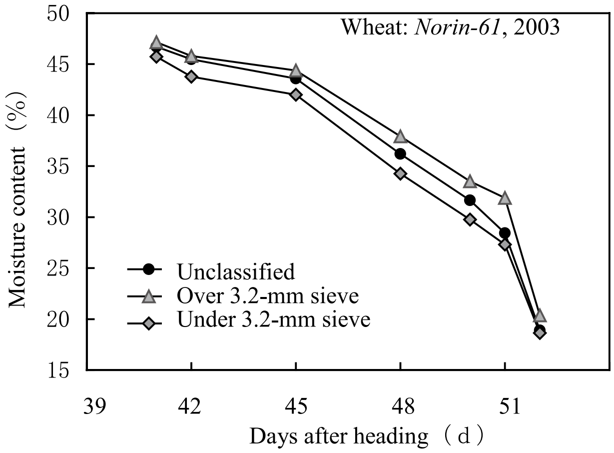


Fig.5. Change in the moisture content of classified grain*

*1. Moisture content was measured using 10 g of grain heated at 135°C for 24 hours.
2. Samples of each harvesting day were 5-10 kg collected from the well mixed grain discharged by the combine harvester.
3. Classification was made using the rotary thickness grader (A-33, Tiger Kawashima).

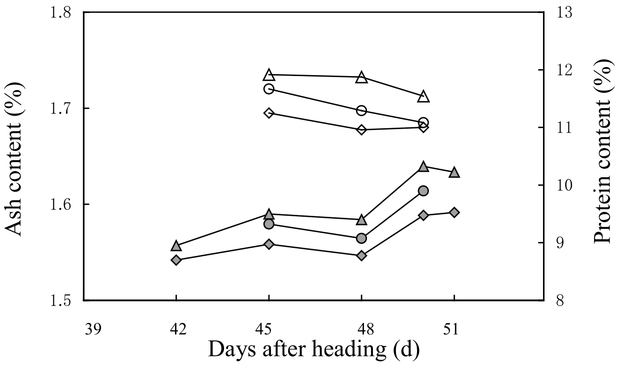


Fig. 6. Ash content and protein content of flour from grain classified by thickness*

* The Japan Grain Inspection Association measured both ash content and protein content.
—○— : Unclassified (Ash content), —△— : Over 3.2-mm sieve, —◇— : Under 3.2-mm sieve, —●— : Unclassified (Protein content), —▲— : Over 3.2-mm sieve, —◆— : Under 3.2-mm sieve

(2) Classification result

Grain classification was done using a 3.2-mm sieve. Figure 7 shows the classification and moisture content of the classified groups. Note that rainfall 54 or 55 days after heading raised the moisture content of the grain.

(3) No airflow drying and flour color

A sample was filled in a beaker (with the top left open) and then dried in an oven for 24 hours under the no airflow condition. The drying temperatures were set at 40°C, 50°C, and 60°C. After no airflow drying, the moisture content of the samples was only 2 to 5% below the initial moisture content. After the drying process, the samples were kept under 10°C in a refrigerator for about three months before milling. The moisture content of all the samples was about 9% when milled using the Quadrumat Junior (Brabender GmbH & Co. KG). The color of flour was measured using a spectral diffraction colorimeter (CM3500; Konica Minolta Holdings).

Figure 8 shows the flour color of grain after no airflow drying. Higher *L**, lower *a**, and higher *b** are preferable as flour color indices. *L** of thicker groups (over the 3.2-mm sieve) was relatively lower (worse), while unclassified and thinner groups (under the 3.2-mm sieve) were almost the same when dried at 40°C, 50°C, and 60°C. The samples dried at 60°C had relatively lower values among all classification groups.

*a** of thicker groups was relatively higher (worse) when dried at 40°C, 50°C, and 60°C. The samples dried at 60°C had relatively higher values among all classification groups.

*b** of thicker groups was relatively lower (worse) when dried at 40°C and 50°C. The samples dried at 60°C had relatively higher values among unclassified and thicker groups.

Based on the results, the thinner groups showed better flour color than unclassified and thicker groups, and showed worse flour color when dried at 60°C than when dried at 40°C or 50°C.

(4) Thin layer drying and flour color

Thin-layer drying samples were spread on a screen with sufficiently small holes and dried in an oven for 24 hours at 50°C and 60°C, respectively. After thin layer drying, the samples showed moisture content of 10 to 13%. After the drying process, the samples were kept under 10°C in a refrigerator for about three months before milling. The moisture content of all samples was about 9%.

Figure 9 shows the flour color of grain after thin layer drying. *L** of thinner groups was higher than of unclassified groups when dried at 60°C. *a** of thicker groups was relatively higher than others when dried at 60°C. *b** was higher in order of the thinner, unclassified, and thicker groups. The unclassified and thicker groups dried at 60°C showed relatively higher values than when dried at 50°C. Based on the results, the color of flour was improved in order of the thinner, unclassified, and thicker groups, and showed worse flour color when dried at 60°C than when dried at 50°C.

(5) Drying condition and starch quality

The starch properties were assessed using a Rapid Visco Analyzer (RVA-3D; Newport Scientific). Figure 10 shows the drying condition and RVA peak value. The value is used as a index of degraded starch quality. A value lower than 300 RVU indicates degraded starch. In Fig. 10, (a) shows the no airflow drying and starch quality. Samples dried at 60°C had a peak value of about 400 RVU, and degradation did not occur. However, the values were not stable for samples dried at 40°C or 50°C, and sometimes low near 300 RVU without thinner samples. In Fig. 10, (b) shows the thin layer drying and starch quality. The classification and drying condition suggested no effect on starch quality.

(6) Conclusions

The thicker group had higher initial moisture content, resulting in easier discoloration of the flour. The starch quality of the thinner group, which had low initial moisture content, was difficult to degrade, but that of a thicker grain (having higher initial moisture content) was easily degraded.

In thin layer drying, the drying temperature did not affect flour quality. In no airflow drying, drying at 40°C degraded starch quality, drying at 60°C discolored the flour, and drying at 50°C caused no major degradation. These results show that drying at 40°C without airflow degrades the grains, and that drying at 60°C with sufficient airflow does not cause degradation, even at initial moisture content higher than 30%.

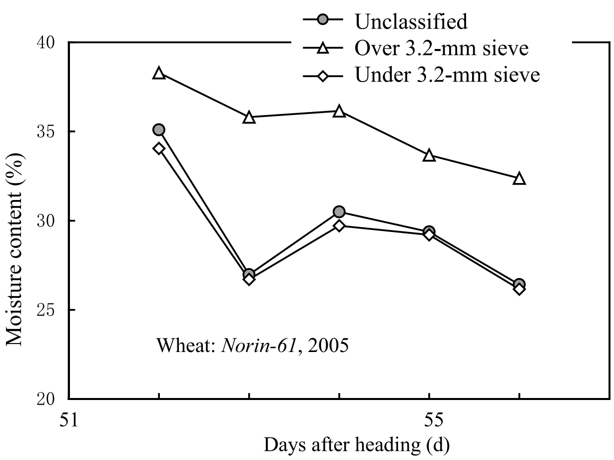


Fig. 7. Moisture content of classified grain*

*1. Moisture content was measured using 10 g of grain heated at 135°C for 24 hours.
2. Samples of each harvesting day were 5-10 kg collected from the well mixed grain discharged by the combine harvester.
3. Classification was made using the rotary thickness grader (A-33, Tiger Kawashima).

6. Practical examination of classification drying[6]

A practical examination was conducted on classification drying here to grasp the practical benefits and problems of this method.

In 2005, wheat samples (Norin-61) were cultivated normally in Ibaraki prefecture, Japan, and then harvested three times: at 46, 49, and 51 days after heading. The classification was made using a rotary grader equipped with a 3.2-mm sieve (A-66, Tiger Kawashima). The classified and non-classified grain groups were examined for flour quality after being dried by a circulating batch drier (Iseki GA-100, with wheat capacity of 1200 kg).

Table 3 lists the test results. Test (A) was conducted as the preliminary test and the amount dried was not measured. The thicker samples had higher moisture content; the thinner samples had lower moisture content. Given the different initial moisture content of the grain groups, the circulating batch drier completed the drying of almost equal amounts of grain in order of the thinner, unclassified, and thicker groups. Thicker grains required seven more hours to complete drying than the time needed for thinner ones to complete drying in test (B).

In terms of actual grain content, the thicker grain group showed a higher ash content and protein content than those of the thinner grain group. Unclassified grains have a median value. The flour of thicker grains also has a higher ash content and protein content than those of

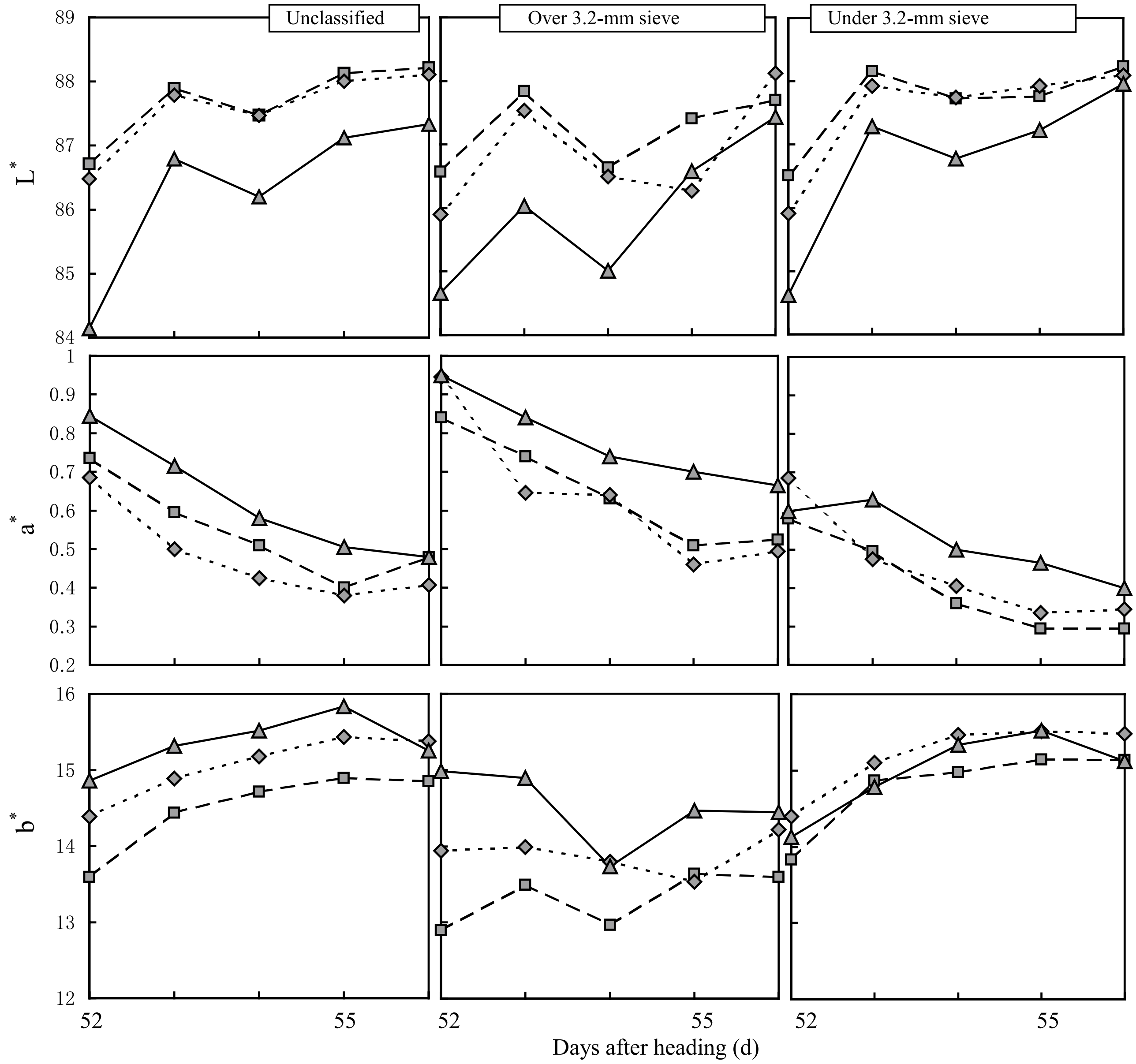


Fig. 8. Color of flour from grain dried without air circulation (2005)*

*1. Milled using the Quadrumat Junior (Brabender GmbH & Co. KG).
2. Measured using CM3500 (Konica Minolta Holdings).
Drying temperature : --■-- : 40°C, --◆-- : 50°C, —▲— : 60°C.

thinner grains, with unclassified grains showing a median value. These tendencies are the same as shown in Fig. 6.

The color of flour as evaluated using the color grader value (CGV) was found preferable in order of the thinner, unclassified, and thicker groups, which is opposite that of the order of ash content and protein content, both of which are believed to degrade the color of flour.

Amylograph, farinograph and extensograph tests indicated that the groups have different dough properties, but no group showed any degradation.

Conclusions

This study clarified the relation between grain thickness and moisture content before the drying process, and demonstrated the possibility of using the new method of classification drying. Based on the results, we found that a 3.2-mm sieve was optimal for a roughly uniform separation of grains having moisture content of around 35%. For the drying process, the thicker grain group had higher moisture content and its flour was vulnerable to discoloration and degraded starch quality. Moreover, we found that it is important to leave grains of high moisture con-

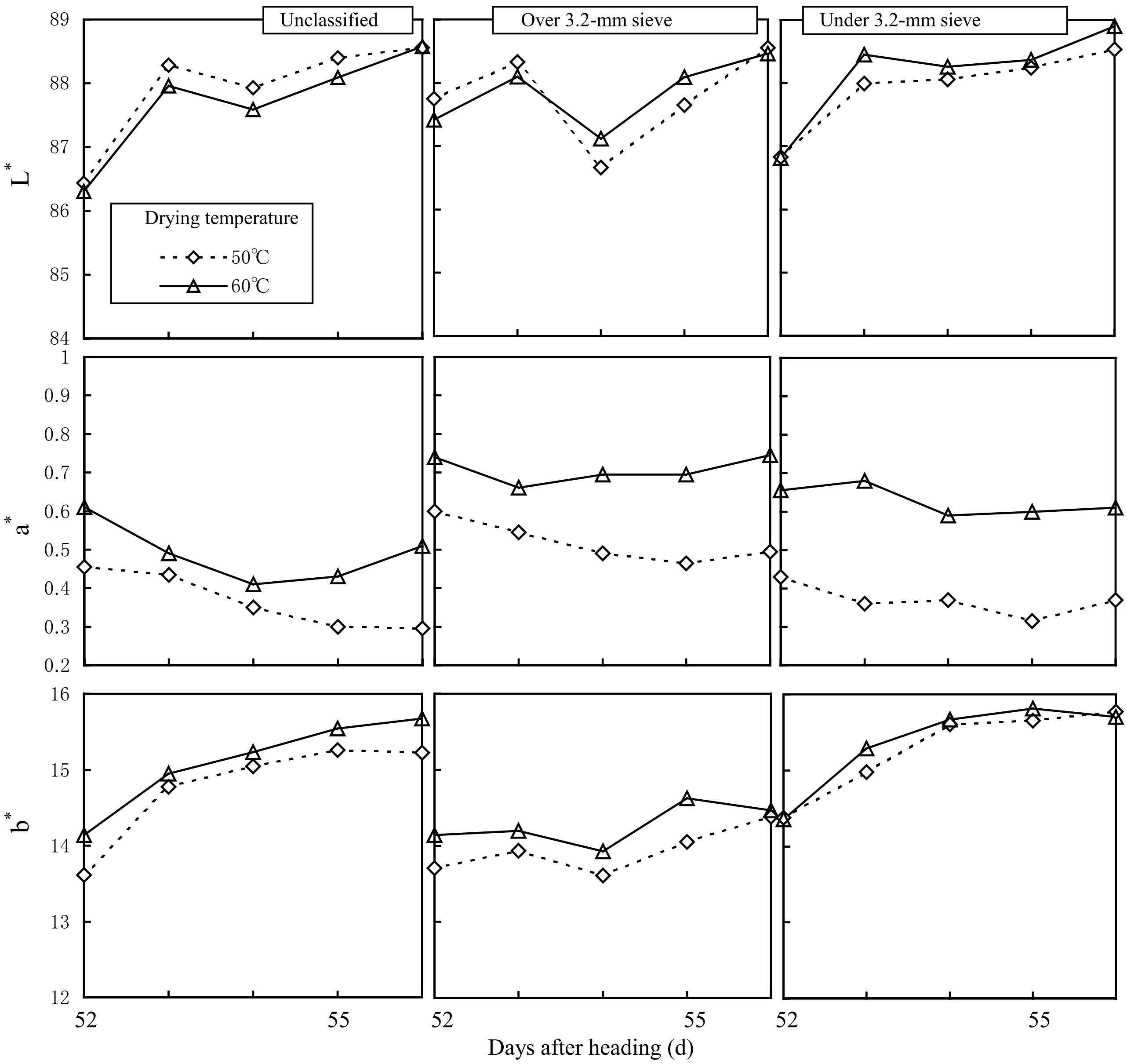
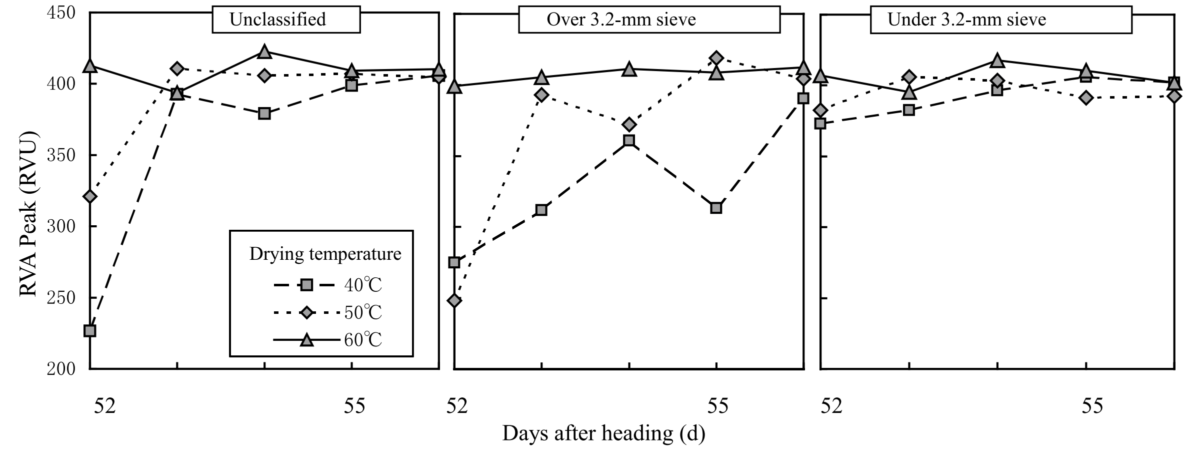


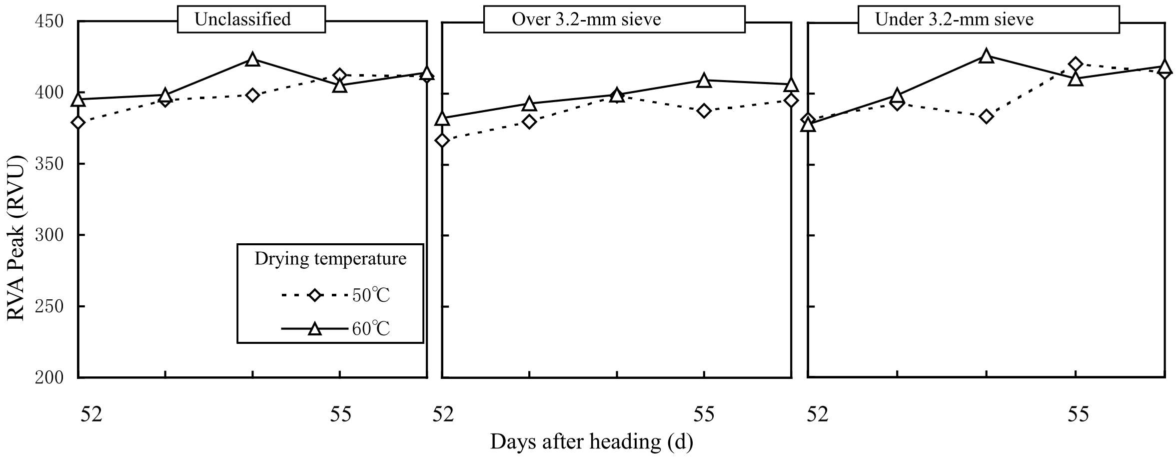
Fig. 9. Thin-layer drying and the color of flour (2005)*

*1. Milled using the Quadrumat Junior (Brabender GmbH & Co. KG).

2. Measured using CM3500 (Konica Minolta Holdings).



(a) The starch quality of flour of grain dried without air circulation



(b) Thin-layer drying and starch quality

Fig.10. The effect of drying condition of grain on starch quality*

*1. Milled using the Quadrumat Junior (Brabender GmbH & Co. KG).
2. Measured using RVA-3D (Newport Scientific).

Table 3. Results of classification drying test with circulating batch drier*

		Initial moisture content (%)	Final moisture content (%)	Duration of drying (h)	Mean drying (%/h)	Loading amount (kg)	Bulk density (g/l)
(A) 46 days after heading (14 June 2005)	Unclassified	46.3	12.6	18	1.9	No-data (300–400 kg)	No data
	Over the 3.2-mm sieve	51.9	11.8	18	2.2		
	Under the 3.2-mm sieve	40.9	11.8	12	2.5		
(B) 49 days after heading (17 June 2005)	Unclassified	39.9	12.9	21	1.4	700	827
	Over the 3.2-mm sieve	41.5	12.5	22	1.6	750	839
	Under the 3.2-mm sieve	37.0	13.3	15	1.2	650	816
(C) 51 days after heading (19 June 2005)	Unclassified	36.0	13.1	17	1.1	900	840
	Over the 3.2-mm sieve	37.9	12.5	17	1.4	500	844
	Under the 3.2-mm sieve	33.3	13.4	18	1.0	950	835

*Bulk density was measured after purification using the 2.2-mm sieve.

tent—the thicker grain group in classification drying—exposed to airflow in order to prevent degraded quality. Practical experiments conducted with a circulating batch dryer showed that the thinner grain group having lower moisture needs less time for drying due to the lower initial moisture content. The color of flour was preferable in order of the thinner, unclassified, and thicker groups. These same tendencies were confirmed in a small sample test. Although the classified groups have different dough properties, no group showed any degradation.

References

1. Kanai, G. et al. (2005) Harvesting conditions and quality of the high moist wheat with a head-feeding combine. *J. Jap. Soc. Agric. Machin.*, **67**, 96–105.
2. Kanai, G. et al. (2006) High-moisture wheat harvesting conditions and quality using an ordinary-type combine. *J. Jap. Soc. Agric. Machin.*, **68**, 87–95.
3. Kanai, G. et al. (2006) Size-grading of high-moisture wheat grain sorted by moisture content. *J. Soc. Agric. Struc. Jap.*, **37**, 11–18.
4. Kanai, G. et al. (2007) Development of classification drying of high moisture wheat grain according to the moisture content. *J. Soc. Agric. Struc. Jap.*, **37**, 199–206.
5. Kanai, G. (2007) Research and development to advance harvesting and drying processes adapted to high-moisture wheat grain. Doctoral thesis at Tsukuba Univ., Kou-4317.
6. Kanai, G. et al. (2007) Development of classification drying of high moisture wheat grain according to the moisture content. *J. Soc. Agric. Struc. Jap.*, **38**, 1–8.