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(1) Physical properties of Yellow Alkaline Noodles from Near-isogenic Wheat Lines with Different Wx Protein Deficiency

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Abstract

This paper reports the results of a study of the relationship among the amylose content of flours and the physical properties, such as the texture, of the yellow alkaline noodles (YAN). For this purpose, we used eight types of near-isogenic flours with different Wx protein deficiency under the Chinese Spring genetic background. With the use of the near-isogenic lines, it was possible to achieve similar flour characteristics, with the exception of the amylose content of starch in YAN, and to analyze clearly the effects of the amylose content on the physical properties of YAN. The results of this study indicated that the breaking force and breaking force/breaking deformation of YAN made from the eight lines basically decreased and that the elastic index, on the contrary, increased when the amylose content of starch from the flours was lower. The breaking force and elastic index of gels from the flours and starches of the eight lines showed similar tendencies to those described above with regard to YAN. These results showed that the physical properties of YAN are greatly influenced by the amylose content of the flour and the properties of the starch gel. A sensory evaluation of YAN indicated that noodles from the flours of single-null types, which lack either the Wx-A1 or the Wx-B1 protein but particularly the former, had somewhat lower hardness, and better elasticity and smoothness than those made from flour having all three *Wx* genes. The results basically corresponded to those of the physical properties of boiled YAN. These facts suggest that wheat with a somewhat low amylose content, when compared to wild-type wheat, is suitable for producing YAN with acceptable texture, especially when considering the elasticity and smoothness.

1 Introduction

Japan is dependent on imported wheat for the production of YAN because of the lack of sufficient domestic wheat suitable for YAN. However, there is a strong consumer demand for YAN made with Japanese flour. Therefore, because it is important that Japan produce domestic wheat suitable for making YAN, the characteristics of flour that is suitable for the production of YAN are analyzed in this study. There is much less information available on YAN than on white salted noodles (WSN), particularly concerning the characteristics of the flour. In general, the texture most desirable for YAN has a specific degree of hardness, elasticity, and smoothness [1]. Reports have shown that the higher protein content of flour is associated with a harder bite and higher degree of elasticity and negatively correlated with the smoothness of the noodle surface and color of YAN [2, 3, 4, 5]. Reports have also shown that the starch properties are also an important factor affecting the eating quality of YAN.

Some workers have reported that starch with higher swelling power and peak paste viscosity is
negatively correlated with the hardness and elasticity and positively correlated with the surface
smoothness of cooked noodles [2, 5, 6]. However, the relationship between the starch properties and
eating quality of YAN has not yet been researched in detail.

Recently, Miura et al. developed eight possible genotypes of near-isogenic lines with different
null *Wx* alleles under the Chinese Spring (CS) genetic background [7]. In their results, the amylose
content in this series varied from less than 3% in waxy CS to about 25% in normal CS, and there
were no significant differences in the time of emergence, plant height, or grain yield. Granule-bound
starch synthase, also referred to as Wx proteins, is the key enzyme involved in the production of
amylose. In cereals, the Wx protein is encoded by the *Wx* locus. Hexaploid wheat carries
homoeologous three *Wx* loci, *Wx-A1*, *Wx-B1*, and *Wx-D1*, on chromosomes 7AS, 4AL, and 7DS,
respectively [8]. Mutations at all three loci result in fully waxy or amylose-free wheat [9]. The lack of
the Wx-B1 protein due to the null *Wx-B1b* allele is the most potent factor reducing the amylose
content [10]. The amylose content has been found to affect the starch gelatinization, pasting, and
gelation properties [11, 12, 13]. Generally, a lower amylose content corresponds to higher peak paste
viscosity and breakdown. Zhao et al. provided evidence for the genetic association of the null
Wx-B1b allele with a high peak viscosity [14]. This model, in which a low amylose content due to the
null *Wx* alleles is always responsible for a higher peak viscosity, was adequate for *Wx-B1b* and
Wx-D1b but not for *Wx-A1b* [12]. Furthermore, we have recently turned our attention to the precise
influence of a reduction in amylose content on the physical properties and eating quality of WSN.
This was accomplished by using the above eight genotypes of near-isogenic wheat with different
compositions of the Wx proteins involved in amylose synthesis. We indicated that the flours of
single-null types, which lack either the Wx-B1 or Wx-D1 proteins, and double-null types, which lack
the Wx-A1 and Wx-D1 proteins, especially the latter, were suitable for making WSN with a desirable
texture [15]. However, the influence of the starch properties on the physical properties and eating
quality of YAN has not been studied by using the near-isogenic series listed above. As shown above,
the desirability of YAN is influenced by the starch and protein. Therefore, experiments using wheat
with a different genetic background have limited value for determining the precise effects of the
differences in the characteristics of the starch and amylose content on the desirability of YAN.
However, using near-isogenic lines, it is possible to achieve similar flour characteristics of YAN, with
the exception of those of the starch; the amylose content and associated starch properties may vary to
some extent.

In this study, we examined the differences in the characteristics of the starch and amylose content

1   and how they influence the physical properties and desirability of YAN made from the eight types of

2   near-isogenic wheat.

3

4   ## 2 Materials and Methods

5   ### 2.1 Wheat, flour, and starch samples

6   A near-isogenic series of eight genotypes having different Wx protein deficiency (Tab. 1) and a

7   control, Australian prime hard wheat (PH), were used in this study. The population was developed

8   from F_1 plants produced between the CS and the waxy CS by the double-haploid method [7]. They

9   were sown in late April, 2001 in a Memuro test field at the National Agricultural Research Center for

10   the Hokkaido Region, Memuro, Hokkaido. Each of the eight types was grown in an experimental plot

11   consisting of two 8m rows with 72cm row width under standard field management. The near-isogenic

12   series was grown under a transparent plastic roof to prevent rain damage for two weeks before

13   maturity. Plants and seeds were individually harvested at maturity.

14   Wheat samples were tempered and milled with a Bühler test mill (Bühler Inc., Uzwil,

15   Switzerland) to produce 60% extraction flour (flour). Starch from each flour sample was isolated by

16   the method of Oda et al. [16]. Flour (50g) and water (about 30ml) were mixed to form a dough ball.

17   The dough ball was left in cold distilled water for 60 min and then hand-kneaded under water until all

18   starch granules were extracted. The starch suspension was sieved with a 45-μm sieve. The filtrate

19   was allowed to stand for at least 3hrs to precipitate the starch. The supernatant was discarded, and the

20   starch sediment was washed twice with water and 80% acetone and then air-dried. The moisture

21   content was estimated by oven-drying 1g of a sample at 115 $^{\circ}$C for 3 hrs.

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23   ### 2.2 Flour and starch properties

24   The amylose content of all samples was determined by the Concanavalin A method using an

25   amylose/amylopectin assay kit (Megazyme Inc., Wicklow, Ireland) [17]. The protein content of the

26   flour was measured using a near-infrared reflectance instrument (Inframatic 8120, Per Con Co.,

27   Hamburg, Germany). The ash content of the flour was measured by the method of the American

28   Association of Cereal Chemists [18]. The pasting properties of the flour were measured by using a

29   Rapid Visco Analyzer (RVA-4, Newport Scientific Pty. Ltd., Warriewood, Australia). Each type of

30   flour (2.82g, dwb) was mixed with 25.0 ml of distilled water to create a 10.0% flour suspension

31   (w/w), and the suspension was heated to 95 $^{\circ}$C at the rate of 12.6 $^{\circ}$C /min, held at 95 $^{\circ}$C for 5 min,

32   and then cooled to 50 $^{\circ}$C at the rate of 11.8 $^{\circ}$C/min. The peak viscosity, breakdown (difference

33   between the peak and minimum viscosity), setback (difference between the final and minimum

1   viscosity), and pasting temperature were recorded. All values for the viscosity parameters were

2   expressed in RVA units (RVA).

3

4   **2.3 Preparation and physical property measurements of YAN**

5   YAN were basically prepared following a procedure based on a standard Japanese method [19].

6   To scale down the noodle test, YAN were prepared on a scale based on 50g of flour. The ingredients,

7   50g of flour (13.0%, mb), 16ml of distilled water, and 0.5g each of salt and *kansui*

8   (K_2CO_3:Na_2CO_3=6:4), were mixed using a mixer (KN-60, MK Co., Chikuma, Japan) for 10 min. Salt

9   and *kansui* were dissolved in the water before use. After mixing, the crumbly dough mixture was

10   transferred to a noodle-sheeting machine (NO. 2485, Sanwa Co., Sapporo, Japan), passed through

11   rollers 3.0mm apart, folded, and then sheeted using the same space between rollers. The same folding

12   and sheeting were performed again, and then the dough sheet was placed in a polyethylene bag for 70

13   min at 20 °C. The sheet was passed between the rollers three times with the clearance progressively

14   reduced to 2.2, 1.4, and ≈1.1 mm (the final thickness of the sheeted dough was adjusted to 1.7 mm).

15   The sheet was cut into noodle strips of ≈ 30 cm in length using No. 20 cutting rolls with 1.5 × 1.4mm

16   cross section. The raw noodles were cooked in 3 l of boiling water for 3 min, kept in hot water for 0

17   or 7 min, and then left in a 20 °C water bath for 3 min to give constant temperature. The moisture

18   content of the cooked noodles was measured by drying for 3 hrs at 135 °C. Surface water on the

19   noodles was removed by wiping with tissue paper, and small pieces of boiled noodles (approximately

20   10g) were cut off before moisture determinations were made. Instrumental texture determinations

21   were basically performed using a RHEONER (model RE-33005, YAMADEN Co., Ltd., Tokyo,

22   Japan) fitted with a 2000g-load cell by the method of Ishida et al. [15]. A cutting test using raw and

23   boiled noodles was performed using a cutting plunger (Type No.21, YAMADEN Co., Ltd., Tokyo,

24   Japan) at a speed of 5mm/sec. The noodles, cut into 5cm lengths, were placed in the center at right

25   angles to a slot on the sample table (Type No.102, YAMADEN Co., Ltd., Tokyo, Japan) and cut

26   crosswise with the stainless cutter of the cutting plunger. From the force-deformation curves, the

27   maximum cutting force (breaking force) and breaking deformation were determined, and the

28   breaking force/breaking deformation value (BF/BD) was calculated.

29   Elasticity, another physical property of a boiled noodle, was measured according to the method

30   described by Tanifuji et al. [20] by using the RHEONER with a wedge-shaped plunger (type No.P-31,

31   YAMADEN Co., Ltd., Tokyo, Japan). A strand of boiled noodles (the noodles had been left in a 20 °C

32   water bath for 3 min after boiling) cut into 5cm pieces was placed on a flat plate in the center at a

33   right angle to the plunger and cut at the crosshead speed of 1 mm/sec. From the force-deformation

curve as well as the above-described cutting test, the rupturing force (F) and force (f) at 1 mm of the strain were measured, and the elastic index was calculated as the ratio of F/f.

2.4 Preparation and physical property measurements of flour and starch gels

The gels of flour and starch were prepared as follows. The gelatinization of flour and starch was achieved in an RVA. The RVA conditions were equivalent to those described above, except that a solution containing 0.13% each of salt and *kansui* (w/w), rather than distilled water, was used and cooling was stopped at 70 $^{\circ}$C. The obtained 6g of paste was placed in a 50ml plastic tube with a flat bottom. The tube was centrifuged at 1500g for 5 min in order to remove bubbles from the paste and to prepare the gel in a cylindrical form of 2.5cm diameter and 1cm height. Afterwards, the tube was kept in a water bath at 20 $^{\circ}$C for 2hrs to completely change the paste to a gel. A compression test of the flour and starch gels was also done with the RHEONER. Flour and starch gels were placed in the center of the RHEONER table, and the gels were compressed to 90 % of the original thickness with the use of a circular 16mm-diameter plunger (Type No.3, YAMADEN Co., Ltd., Tokyo, Japan) at a speed of 1 mm/s. From the compression curve, the breaking force (BF), force (f) at 3mm of the strain, and breaking deformation (BD) were determined, and the BF/BD and elastic index, BF/f, were calculated.

2.5 Sensory evaluation of YAN

The sensory evaluation of boiled YAN was accomplished according to procedures based on the method of Akashi et al. [21] with the addition of an evaluation for smoothness. Trained panelists performed a sensory evaluation of the texture of YAN. This assessment included three parameters: hardness, elasticity, and smoothness. Elasticity, as defined in this sensory evaluation, is different from gumminess. It is the noodle physical property of glutinosity (but no sticky) and shortness. PH was used for the standard sample. Each parameter was evaluated in a ten-grade. The sample noodles were compared with a noodle prepared from the standard sample. The standard sample was allocated scores of 5.0 for each of three parameters. Higher scores indicated more desirable textures.

2.6 Statistical analysis

The amylose content of starch from flours, analytical data of flours, except for the ash content, and pasting properties of flours were measured in triplicate. The ash content was measured in duplicate. The measurements of the physical properties of noodles and gels were repeated four and three times, respectively. The sensory evaluation of boiled noodles was conducted by six panelists.

All data are shown as a mean, and the significance of the difference between each bit of data was evaluated by an analysis of variance using Duncan's multiple range test.

3 Results and Discussion

3.1 Amylose, protein, and ash contents

A large variation was found in the amylose content of starch among the eight types of Wx protein deficiency wheat samples (Tab. 1). Type 1 (CS), which produces all three of the Wx proteins, had around 24% amylose. As anticipated, Type 8 (waxy CS) did not synthesize amylose and was thus regarded as amylose-free. In the remaining six types of Wx protein-deficient lines (Types 2-7), the amylose content was distributed between these two extremes. The amylose contents of Types 2, 3, and 4 of the single-null types were about 2-3% lower than that of Type 1, which produced around 24%. In starches of the double-null Types 5, 6, and 7, a reduction in the amylose content of about 5-7% compared to Type 1 was detected; Type 7 had the lowest amylose content, at about 17%, followed by Types 5 and 6. Comparisons between the single-null and double-null types basically confirmed our previous results [7, 22]. The PH had a somewhat lower amylose content than Type 1 (CS) with all Wx proteins. The protein content of the flours varied slightly among the eight types, those of Types 1 and 8 being somewhat higher than those of the other six types. The protein content of these six types was nearly equal. The PH showed a protein content similar to those of Types 1 and 8. The ash content also varied slightly among the eight types. Those of Types 3, 5, 7, and 8 were somewhat higher than those of the other samples. Types 2, 4, and 6 had nearly equal values, and those of Type 1 and PH, especially the latter, had rather low contents. Though the differences of protein and ash contents among the types were observed, we assumed that the *Wx* gene loci and close regions did not greatly influence the protein and ash content of wheat. This is because, in general, the protein and ash contents of flour are influenced by many factors, such as several characteristics of wheat and fine milling conditions.

3.2 Flour properties

The RVA experiments indicated that, in all types, except for Type 8, the peak viscosity did not differ greatly, and Type 8 (waxy CS) had an extremely low value. PH had a somewhat high peak viscosity. As regards breakdown, all types, except for Type 3, had similar values, and PH had the highest value. The setback values basically decreased when the amylose content was lower, and that of Type 8 was extremely low. Therefore, flour paste with a low amylose content appeared to be difficult to retrograde. The setback of PH had a rather high value. There was a large variation in the

pasting temperature (65.6-76.9). Pasting of the double-null types occurred at around 70 $^{\circ}$C, and this temperature tended to be basically lower than that of Type 1 and the single-null types. Type 8 started to paste at the lowest temperature, 65.6 $^{\circ}$C. The pasting temperature of PH was between those of the double-null types and Type 8. Similar tendencies of the pasting properties were observed using starches from the near-isogenic lines as well as this study, flour and starches from crossbred waxy lines, low-amylose lines, and their parents [22, 23, 24].

3.3 Physical properties of YAN

The measured physical properties of the noodles were the breaking force, breaking deformation, BF/BD, and elastic index (only boiled noodles were measured). The raw noodles were much harder than the boiled noodles. The physical properties of raw noodles are shown in Tab. 2. The properties of seven of the samples were not greatly different, except for those of Type 8 (waxy wheat). From these results, we assumed that the composition of the flour, except for the starch, such as protein and non-starch polysaccharides, was also nearly the same. It has been reported that the β-glucan content in the flour of waxy wheat is higher than that in the non-waxy parent [25]. From our analysis (detailed data not shown), the pentosan and β-glucan contents in waxy wheat flour were also about 0.2-0.3% and 0.08-0.1%, respectively, higher than those in the other types, and the difference among the other types was not significant. Therefore, the increased pentosan and β-glucan contents of waxy flour seemed to influence the physical properties of raw noodles made from waxy flour, whose breaking force and BF/BD are remarkably higher than those of the other types. However, since the contents of pentosan and β-glucan among the seven types, except for Type 8, were not significantly different, we assumed that non-starch polysaccharides did not significantly influence the difference in physical properties among raw and boiled noodles made from the seven types, except for waxy wheat. The raw noodles from PH had lower breaking force and BF/BD and a somewhat large breaking deformation compared to the other types, except for Type 8.

The results of the physical properties of boiled noodles are shown in Tab. 3. As there were no significant differences in the water content of the boiled noodles (data not shown), the effect of the water content was considered to be negligible. The breaking force and BF/BD of boiled noodles made from the eight types tended to basically decrease when the amylose content was lower, and those of Type 8 showed extremely low values. In contrast, the elastic index of noodles just after boiling tended to basically increase as the amylose content was lower. On the other hand, there were no great differences in the elastic index of any of the noodles at 7 min after boiling or in the breaking force, breaking deformation, and BF/BD of the samples, except for those of Type 8, which had

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significantly different values. The overall physical properties of boiled noodles from PH were basically similar to those between single-null and double-null types. Those results suggest that a lower amylose content or an increase in amylopectin produces softer and more elastic noodles after boiling, especially just after boiling. This is because the BF/BD and elastic index as an index of elasticity of the noodles just after boiling respectively decreased and increased according to the amylose content in the following order: wild, single-null, double-null, and waxy types. From these results, it is clear that the physical properties of boiled noodles, especially the hardness and elasticity, depend on the amylose content of flour from the near-isogenic lines. It has been previously reported that the amylose content and associated starch properties have a partial relationship with the physical properties and texture of YAN [5, 6, 21, 26, 27, 28]. The results given here provide substantial evidence that the previous reports were correct.

3.4 Physical properties of flour and starch gels

The physical properties of flour and starch gels are shown in Tab. 4. It was impossible to measure the physical properties of gels from Type 8 because they were too soft. The breaking force and BF/BD values of gels from the seven types, except for Type 8, tended to decrease, as did the breaking force and BF/BD of boiled noodles, when the amylose content was lower. In contrast, the elastic index of both gels basically increased according to the lowering of the amylose content, as in the case of the noodles just after boiling. On the other hand, the breaking deformation of both gels did not show a large difference as well as that of boiled noodles. The breaking force and BF/BD values of PH were rather large compared to those of Type 1, and the breaking deformation was smaller than those of the seven types. The elastic index value of the PH gels was between those of the wild type and single-null types. The decrease of the breaking force and BF/BD values and increase of the elastic index in both kinds of gels were sharper and clearer than that of each value of the boiled noodles. Although the physical properties of both gels and boiled noodles basically changed in parallel with the decrease in the amylose content, the association between the amylose content and the physical properties was the greatest in starch gel followed by flour gel and boiled noodles. The difference between gels and boiled noodles seemed to be influenced by the composition, water content, and starch gelatinization condition, etc. The above results suggested that the starch gel properties in the boiled noodles significantly influenced their physical properties and that the gel properties were chiefly determined by the amylose content. The amylose content of PH was somewhat lower than that of Type 1, but the breaking force and BF/BD of both gels from the PH showed rather large values compared to those of Type 1. As the reason, the values seemed to

1 be related to the differences in protein quality and characteristics of the starch, except for the

2 amylose content between PH and the seven types. The starch gelatinization, swelling, gelation

3 properties, and other physical properties of the gel are known to be affected by the amylose content

4 [15, 24]. Our results suggest that the physical properties of the starch gel in YAN, in particular, in

5 noodles made from the near-isogenic wheat series, which have a nearly identical genetic

6 background except for the starch properties, mostly reflect the properties of boiled YAN because of

7 the effects of the amylose content on the subsequent process on starch gelatinization.

8

9 **3.5 Sensory evaluation of YAN**

10 The background cultivar, CS, is the representative spring wheat for genetic analysis, but it is not

11 profitable for breeding. Therefore, when this study was planned, it seemed that the general

12 characteristics of the CS flour, especially regarding protein, differed significantly from those of the

13 most popular brand of flour used for YAN, i.e., PH. However, unexpectedly, the sensory evaluation

14 confirmed that the quality of the noodles from eight types, except for Type 8, was similar to that of

15 PH and showed rather clear results. Namely, the score of hardness among the eight types basically

16 decreased when the amylose content was lower. The elasticity, smoothness, and total score of noodles

17 from the eight types, except for Type 8, were similar to or better than those of PH. Those of Type 2

18 (Wx-A1 protein deficiency) were especially good. These results demonstrated that the comparison of

19 the near-isogenic eight types was valid and that the amylose content in flour influenced the texture of

20 YAN. Furthermore, it was suggested that an amylose content of about 22%, which is a somewhat

21 lower value than that of wheat having all three *Wx* genes, was suitable for the production of YAN

22 with good eating texture, especially for elasticity and smoothness, and that cultivars having either

23 null *Wx-A1b* or null *Wx-B1b* would be adequate.

24 These results corresponded to those of reports that PH with a somewhat lower amylose content

25 showed better elastic texture than Hard Red Winter and that the Australian cultivar having the null

26 *Wx-B1b* gene had good smoothness compared to the wild-type cultivar [5, 21].

27

28 **3.6 Relationship among the amylose content and physical properties of boiled noodles**

29 **and gels**

30 The correlation coefficients among the amylose content and physical properties of boiled noodles

31 (noodles immediately after boiling) and both gels of the seven types, except for Type 8, in the case of

32 gels are shown in Tab. 6. The amylose content was significantly correlated with breaking force,

33 BF/BD, and elastic index of boiled noodles and both gels, but there was no significant correlation

between the amylose content and breaking deformation. These results proved that the amylose content of the flours greatly influenced the breaking force as an index of hardness and the BF/BD and elastic index as indices of elasticity and that noodles with a soft and elastic texture were obtained when the amylose content was decreased. The results were in good agreement with those from studies about the relationship between the amylose content and the physical properties of noodles, which were investigated in detail using noodles that were not similar to YAN [15, 28]. In this study, near-isogenic lines, which were nearly identical in genetic background except for the amylose content, were used. Therefore, the reliability of the analytical results of the data appears to be very high. It is clear that the genetic background in the near-isogenic series, except for the amylose content, is almost identical because of the variation in the agronomical characteristics and the chain length distributions (DP<36) of their amylopectins, which were insignificant [7]. The changes in the physical properties of YAN with the reduction in the amylose content seemed to have been caused by the changes in the physical properties of the starch gels in YAN. This is so because, in the flour and starch gels, both of which contain 1 % salt and *kansui* per the powder, the correlation between the amylose content and the values of various physical properties showed a tendency similar to that noted in boiled noodles. The breaking force of boiled noodles was positively and negatively correlated significantly with the BF/BD and the elastic index as an index of elasticity, respectively, and significantly correlated with the breaking force and BF/BD of the starch gel. These results showed that the hardness and elasticity of boiled noodles are contradictory properties and that the elasticity (viscoelasticity) of noodles tends to increase as the hardness decreases. Physical properties, such as the breaking deformation, did not seem to show a fixed tendency with the fluctuation in the amylose content because a generally high correlation between the breaking deformation and the values of variable physical properties was not observed except in a few cases. Although the BF/BD of boiled noodles was highly correlated with the elastic index, there was not a significant correlation between the value and all physical properties of both gels. On the other hand, the elastic index of boiled noodles showed a correlation with the breaking force and BF/BD of flour gel, and breaking force and elastic index of starch gel. From these facts, the value of the elastic index of boiled noodles seems to be effective for an analysis of the viscoelasticity of YAN boiled noodles, including the gel properties. There was a very high and significant correlation among all physical property values except for the breaking deformation on the flour and starch gels. The correlation among the variable physical properties of each gel also showed a similar tendency in both gels. From these results, the components, except for starch, do not seem to impart significant changes in the physical properties of flour gel as the amylose content varies. They seem to be related to the fact that near-isogenic series

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were used in this experiment.

Like the above, the changes in the fundamental physical properties of both gels were similar to those in boiled noodles. However, the gelation condition of the starch differed significantly from that in boiled noodles. From the results of Tabs 3 and 4, the changes of gel's physical properties were sharper than those of boiled noodles. They seem to be related to that the internal structure and shape on both gels were uniform and constant compared to those of boiled noodles. Therefore, it would seem worthwhile to investigate the gel properties in conjunction with the physical properties of the noodles when the effect of the starch characteristics for noodle physical properties is analyzed. In general, YAN with a hard texture with moderate elasticity and good smoothness are considered to be the best physical properties, which is different from those of WSN. Therefore, flour with a somewhat higher amylose content as compared to the case of WSN is more suitable for making YAN. In this study, the results shown in Tab. 5 demonstrate that the noodles made from Types 2 and 3, which have a somewhat lower amylose content, had a good texture, especially with regards to elasticity and smoothness, but those from the double-null types, which were determined to be good for producing a WSN with good texture, were inferior to those of Types 1 and 2. It was suggested that an amylose content of about 22%, a somewhat lower value than that of wheat having all three *Wx* genes, was suitable to produce YAN with good eating texture and that cultivars having either the null *Wx-A1b* or the null *Wx-B1b* would be adequate for making YAN with good texture.

4 Conclusions

In the present study, we examined the relationship between the physical properties and eating texture of YAN and the amylose content of flour starch using eight types of Wx protein-deficient near-isogenic series with a CS genetic background. The hardness and elasticity of YAN and the flour and starch gels of the eight types basically decreased and increased, respectively, with a reduction in the amylose content of the starch. Softer and more elastic YAN, especially upon evaluation of the physical properties, were obtained from types with a lower amylose content. From these results, it was evident that the physical properties of boiled YAN were influenced by the starch properties, such as the amylose content, because the amylose content greatly affected the physical properties of the flour and starch gels. The sensory evaluation of YAN showed that a somewhat lower amylose content, of about 22%, than that of a wild-type flour, such as Type 1, was associated with YAN with good eating texture, especially with regards to elasticity and smoothness, and that the cultivars with the null *Wx-A1b* or *Wx-B1b* have a valid potential to produce YAN with good texture. Our results may provide useful information for wheat breeders and users.

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