



Physical properties of yellow alkaline noodles from near-isogenic wheat lines with different Wx protein deficiency

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| 著者 (英) | Tanaka Yuko, Miura Hideho, Fukushima Michihiro, Ito Miwako, Nishio Zenta, Kim Sun-Ju, Hashimoto Naoto, Noda Takahiro, Takigawa Shigenobu, Matsuura-Endo Chie, Yamauchi Hiroaki |
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3 **(1) Physical properties of Yellow Alkaline Noodles from Near-isogenic**
4 **Wheat Lines with Different Wx Protein Deficiency**

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7 (2) Yuko Tanaka ^a, Hideho Miura ^a, Michihiro Fukushima ^a, Miwako Ito ^b, Zenta Nishio ^b, Sun-Ju Kim
8 ^b, Naoto Hashimoto ^b, Takahiro Noda ^b, Shigenobu Takigawa ^b, Chie Matsuura-Endo ^b, and Hiroaki
9 Yamauchi^b

10
11 (3) ^a Department of Crop Science, Obihiro University of Agriculture and Veterinary Medicine,
12 Obihiro 080-8555, Japan

13 ^b Department of Upland Agriculture Research, National Agricultural Research Center for
14 Hokkaido Region, Memuro, Hokkaido 082-0071, Japan

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18 (5) Corresponding author: Hiroaki Yamauchi

19 Address: Department of Upland Agriculture Research, National Agricultural Research Center for
20 Hokkaido Region, Memuro, Hokkaido 082-0071, Japan

21 Tel.: +81 155 62 9278; Fax: +81 155 62 2926; E-mail: yamauti@affrc.go.jp

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1 **Abstract**

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

23 **1 Introduction**

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

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

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

33 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 F₁ 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- μ m 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 °C for 3 hrs.

22 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 °C at the rate of 12.6 °C /min, held at 95 °C for 5 min,
32 and then cooled to 50 °C at the rate of 11.8 °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).

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 1.5×1.4 mm
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

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

3 4 **2.4 Preparation and physical property measurements of flour and starch gels**

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

18 19 **2.5 Sensory evaluation of YAN**

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

28 29 **2.6 Statistical analysis**

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

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

3 **3 Results and Discussion**

4 **3.1 Amylose, protein, and ash contents**

5 A large variation was found in the amylose content of starch among the eight types of *Wx* protein
6 deficiency wheat samples (Tab. 1). Type 1 (CS), which produces all three of the *Wx* proteins, had
7 around 24% amylose. As anticipated, Type 8 (waxy CS) did not synthesize amylose and was thus
8 regarded as amylose-free. In the remaining six types of *Wx* protein-deficient lines (Types 2-7), the
9 amylose content was distributed between these two extremes. The amylose contents of Types 2, 3,
10 and 4 of the single-null types were about 2-3% lower than that of Type 1, which produced around
11 24%. In starches of the double-null Types 5, 6, and 7, a reduction in the amylose content of about
12 5-7% compared to Type 1 was detected; Type 7 had the lowest amylose content, at about 17%,
13 followed by Types 5 and 6. Comparisons between the single-null and double-null types basically
14 confirmed our previous results [7, 22]. The PH had a somewhat lower amylose content than Type 1
15 (CS) with all *Wx* proteins. The protein content of the flours varied slightly among the eight types,
16 those of Types 1 and 8 being somewhat higher than those of the other six types. The protein content
17 of these six types was nearly equal. The PH showed a protein content similar to those of Types 1 and
18 8. The ash content also varied slightly among the eight types. Those of Types 3, 5, 7, and 8 were
19 somewhat higher than those of the other samples. Types 2, 4, and 6 had nearly equal values, and
20 those of Type 1 and PH, especially the latter, had rather low contents. Though the differences of
21 protein and ash contents among the types were observed, we assumed that the *Wx* gene loci and close
22 regions did not greatly influence the protein and ash content of wheat. This is because, in general, the
23 protein and ash contents of flour are influenced by many factors, such as several characteristics of
24 wheat and fine milling conditions.

25 **3.2 Flour properties**

26 The RVA experiments indicated that, in all types, except for Type 8, the peak viscosity did not
27 differ greatly, and Type 8 (waxy CS) had an extremely low value. PH had a somewhat high peak
28 viscosity. As regards breakdown, all types, except for Type 3, had similar values, and PH had the
29 highest value. The setback values basically decreased when the amylose content was lower, and that
30 of Type 8 was extremely low. Therefore, flour paste with a low amylose content appeared to be
31 difficult to retrograde. The setback of PH had a rather high value. There was a large variation in the
32
33

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

8 **3.3 Physical properties of YAN**

9 The measured physical properties of the noodles were the breaking force, breaking deformation,
10 BF/BD, and elastic index (only boiled noodles were measured). The raw noodles were much harder
11 than the boiled noodles. The physical properties of raw noodles are shown in Tab. 2. The properties
12 of seven of the samples were not greatly different, except for those of Type 8 (waxy wheat). From
13 these results, we assumed that the composition of the flour, except for the starch, such as protein and
14 non-starch polysaccharides, was also nearly the same. It has been reported that the β -glucan content
15 in the flour of waxy wheat is higher than that in the non-waxy parent [25]. From our analysis
16 (detailed data not shown), the pentosan and β -glucan contents in waxy wheat flour were also about
17 0.2-0.3% and 0.08-0.1%, respectively, higher than those in the other types, and the difference among
18 the other types was not significant. Therefore, the increased pentosan and β -glucan contents of waxy
19 flour seemed to influence the physical properties of raw noodles made from waxy flour, whose
20 breaking force and BF/BD are remarkably higher than those of the other types. However, since the
21 contents of pentosan and β -glucan among the seven types, except for Type 8, were not significantly
22 different, we assumed that non-starch polysaccharides did not significantly influence the difference in
23 physical properties among raw and boiled noodles made from the seven types, except for waxy wheat.
24 The raw noodles from PH had lower breaking force and BF/BD and a somewhat large breaking
25 deformation compared to the other types, except for Type 8.

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

1 significantly different values. The overall physical properties of boiled noodles from PH were
2 basically similar to those between single-null and double-null types. Those results suggest that a
3 lower amylose content or an increase in amylopectin produces softer and more elastic noodles after
4 boiling, especially just after boiling. This is because the BF/BD and elastic index as an index of
5 elasticity of the noodles just after boiling respectively decreased and increased according to the
6 amylose content in the following order: wild, single-null, double-null, and waxy types. From these
7 results, it is clear that the physical properties of boiled noodles, especially the hardness and elasticity,
8 depend on the amylose content of flour from the near-isogenic lines. It has been previously reported
9 that the amylose content and associated starch properties have a partial relationship with the physical
10 properties and texture of YAN [5, 6, 21, 26, 27, 28]. The results given here provide substantial
11 evidence that the previous reports were correct.
12

12

13 **3.4 Physical properties of flour and starch gels**

14 The physical properties of flour and starch gels are shown in Tab. 4. It was impossible to measure
15 the physical properties of gels from Type 8 because they were too soft. The breaking force and
16 BF/BD values of gels from the seven types, except for Type 8, tended to decrease, as did the
17 breaking force and BF/BD of boiled noodles, when the amylose content was lower. In contrast, the
18 elastic index of both gels basically increased according to the lowering of the amylose content, as in
19 the case of the noodles just after boiling. On the other hand, the breaking deformation of both gels
20 did not show a large difference as well as that of boiled noodles. The breaking force and BF/BD
21 values of PH were rather large compared to those of Type 1, and the breaking deformation was
22 smaller than those of the seven types. The elastic index value of the PH gels was between those of
23 the wild type and single-null types. The decrease of the breaking force and BF/BD values and
24 increase of the elastic index in both kinds of gels were sharper and clearer than that of each value of
25 the boiled noodles. Although the physical properties of both gels and boiled noodles basically
26 changed in parallel with the decrease in the amylose content, the association between the amylose
27 content and the physical properties was the greatest in starch gel followed by flour gel and boiled
28 noodles. The difference between gels and boiled noodles seemed to be influenced by the
29 composition, water content, and starch gelatinization condition, etc. The above results suggested
30 that the starch gel properties in the boiled noodles significantly influenced their physical properties
31 and that the gel properties were chiefly determined by the amylose content. The amylose content of
32 PH was somewhat lower than that of Type 1, but the breaking force and BF/BD of both gels from
33 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.

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].

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

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

1 were used in this experiment.

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

19

20 **4 Conclusions**

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

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