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Hydrothermal treatment of sprout-damaged grain

I. Effects on the technological quality of wheat

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Abstract. Two sprout-damaged wheat lots with the falling number values of 91 and 65 were heat-treated by immersing the grain in water of temperatures of 80, 85, 90 and 100° C, followed by rapid chilling in water. The purpose of the treatment was to suppress the excess α-amylase activity in the outer layers of the kernels. The α-amylase activity following the treatment was measured by the falling number test. The increase in the falling number value was the greater the longer the treatment lasted and the higher the water temperature was. Processing lasting 30 sec at 80, 85, 90 and 100° C increased the falling number value of the one lot from 91 to 105, 117, 133 and 238 and of the other lot from 65 to 69, 70, 98, 163, respectively.

As the falling numbers increased the wet gluten content of the samples decreased. These changes had a negative correlation. The gluten quality showed heat damage when the amount of gluten had dropped by about 5 and 2 precentage units in the lots with the falling numbers 91 and 65, respectively. This occurred at processing of the lot of better quality for 70, 20, 13 and 6 sec in the order of increasing temperature. The corresponding durations for the other lot were above 60, 30, 20 and 6 sec. During these treatments the falling number values rose from 91 to 104—129 and from 65 to 70—71. These results were confirmed by farinogram and extensigram determinations and by baking tests. The same processing conditions affected more severely the lot having the better initial quality than the lot with greater sprout damages.

Introduction

During sprouting the activity of α-amylase in the grain increases exponentially as a function of time (Olered 1963, Dronzek et al. 1972). A high α-amylase activity impairs the baking quality of the flour in that the gelatinized starch is rapidly degraded to water soluble sugars at baking. The gelatinized starch is susceptible to amylase attack until the enzyme is inactivated by heat (Bean et al. 1974). This degradation lowers the water imbibing properties of starch and the crumb of the breads become damp and doughy (Thomas and Luckow 1969).

The amylase activity of grain or flour can be depressed or inactivated by heat or by chemical agents. Under conditions closely resembling those prevailing in wheat bread during baking, about 90 % of the activities of β- and αamylases were destroyed at about 75 and 85° C, respectively (WALDEN 1955). JONGH (1967) showed that the amylases lost their activity at baking when the temperature had risen to about 78° C.

The denaturation of enzyme proteins is catalyzed by water. The water lowers the activation energy of the denaturation reaction (MULTON and GUILBOT 1975). According to this the inactivation of amylases in grain with a low water content needs stronger processing conditions than the same degree of inactivation needs in doughs. On the other hand, low water contents slow down the enzyme reactions as the dissociation of the enzyme-substrate complex is retarded because of low amounts of tree water (REED 1975).

The effects of heat treatment on the other components of the grain have to be taken into account at processing, especially the influence of heat on the gluten proteins which affect the functional properties of wheat. In order to improve the millability and the baking properties of wheat, conditioning has generally been applied in mills (BRADBURY et al. 1960, SCHÄFER and ALTROGGE 1960, KUPRITS 1965).

The denaturation of proteins during hydrothermal treatment is directly dependent on the temperature, the moisture content of the grain and the treatment time (LENARSKII 1960). The effects of these factors on the denaturation of wheat gluten was investigated by PENCE et al. (1953). Denaturation occurred already at 70° C in wheat grain treated for 60 min, and at higher temperatures the denaturation reaction was faster. The bread volumes decreased when the wheat was treated for 20 min at 70° C. Treatment at 85° C for 20 min decreased the bread volumes to half of the initial value. Denaturation was very fast when the moisture content of the gluten at heating was 35—40 % but it slowed down when the moisture content decreased. According to SCHÄFER and ALTROGGE (1960) hot conditioning at 60° C affected the gluten unfavorably, and at temperatures above 70° C the proteins evidently were denaturated. The processings lasted from 20 to 120 min.

After heat treatment of sprouted wheat at temperatures below 50° C an activation of amylases was detected. Steam conditioning above 50° C had a deleterious effect on the gluten, so the gluten of unsprouted wheat seemed to be more thermostable. This was also confirmed by baking tests (ALTROGGE and SCHÄFER 1954, SCHÄFER and ALTROGGE 1960). But according to GAWDA (1973) the quality of wheat containing 3 % of sprouted kernels was improved by heating the grain at 60—65° C.

The α-amylase of germinating seed is synthesized in the aleurone cells in response to gibberellic acid (GIBSON and PALEG 1975). From the aleurone cells the α-amylase moves to the endosperm as the germination process continues. Even at relatively high levels of α-amylase in the whole grain there is initially very little activity within the inner endosperm, so the level of α-amylase is reduced considerably on milling (GUERIVIERE et al. 1969). DREWS and SEIBEL (1976) pointed out that α-amylase in sprouted grain is particularly high in the subaleurone layer. DRONZEK et al. (1972) showed by scanning electron microscopy that in sprouted wheat the granules near the aleurone layer are attacked at an earlier stage of sprouting than granules in the inner endosperm. This also suggests that in sprouted wheat the amylase activity is higher in the aleurone layer. The same research team found that even after eight days of sprouting not all of the granules were eroded by amylases.

The assumption that the starch fraction of sprouted wheat is still of relatively good quality is supported by investigations where the amylase activity has been reduced by chemical agents at dough making or at viscometric determinations (Schulz and Stephan 1960, Clausen 1963, Carter and Hutchinson 1965, Möttönen 1967, Cawley and Mitchell 1968, Bean and Fullington 1970, Fuller 1970, Meredith 1970, Bean et al. 1974).

Sprouting in the ear as a consequence of the rather wet climate at harvest time is a very great grain quality problem in Finland. This study deals with the possibilities to depress the high α-amylase activity of the outer layers of sprouted wheat kernels by means of a momentary hydrothermal treatment. The aim was to restrict the heat treatment to the outer layers of the kernel and so to prevent denaturation of the gluten-forming proteins of the inner endosperm. This treatment was intended to improve the baking properties of sprout-damaged wheat.

Materials and Methods

Two lots of spring wheat received from grain silos of the State Granary were used in the experiments. The lots consisted to 90 % and 70 % of the variety Ruso and the cleaned lots had the falling numbers 91 and 65, respecttively. The crude protein contents of the samples were 16.2 and 14.6 % (d.b.). Samples for heat treatment were taken with a probe divider from the cleaned grain stored at +4° C.

For each heat treatment experiment 500 g of grain with a moisture content of about 14 % was used. The heat treatments were carried out in water baths having the temperatures of 80, 85, 90 and 100° C. During the treatments the grain was enclosed in a metal wire basket having a volume of 2.4 l. The basket was immersed for 10 to 90 sec in hot water (35 l) of the proper temperature ±0.5° C for each treatment. The basket was shaken manually during the whole process. Immediately when a given time had elapsed the basket was transferred to another water bath (40 l) having a temperature of +10° C. The basket was shaken manually also during this chilling process lasting 30 sec. The grain was then enclosed in a cloth and centrifuged in order to remove the excess water from the surface of the kernels. After centrifugation the moisture content of the grain batches varied between 17 and 25 % depending on the intensity of the heat treatment. The grain was dried to a moisture content below 15 % spread out as a thin layer on a tray at room temperature. All the heat treatment experiments were performed in duplicate.

The falling number determinations were made according to the standard method (Anon. 1971). The gluten was washed out by hand as described by Rohrlich and Brückner (1967).

The wheat samples were milled in a Brabender Quadrumat Senior experimental mill. Before milling the grain samples were tempered to about 15 % moisture content. The wheat flours were kept at room temperature for

14 days, after which they were stored at $+4°$ C until analyzed. The ash content of the wheat flours were determined by AOAC method No. 14.007-8 (ANON. 1970).

The farinograms were made according to the AACC standard method for constant flour weight (ANON. 1962) in a Brabender Farinograph having a bronze bowl and paddles. The extensigram determinations followed the AACC standard method (ANON. 1962) and were made in a Brabender Extensigraph. The baking tests were performed as described in an earlier paper (WESTERMARCK-ROSENDAHL 1978).

Results

Initial experiments

Some initial experiments were made to find out the influence of certain factors that may affect the heating process.

A low temperature of the samples may protect the heat-labile protein fraction of the endosperm during heat treatment. Based on this assumption wheat samples (falling number 91) with initial temperatures of $+23$, $+5$ and $-18°$ C were treated at 80 and 100° C. The results collected in Fig. 1 show

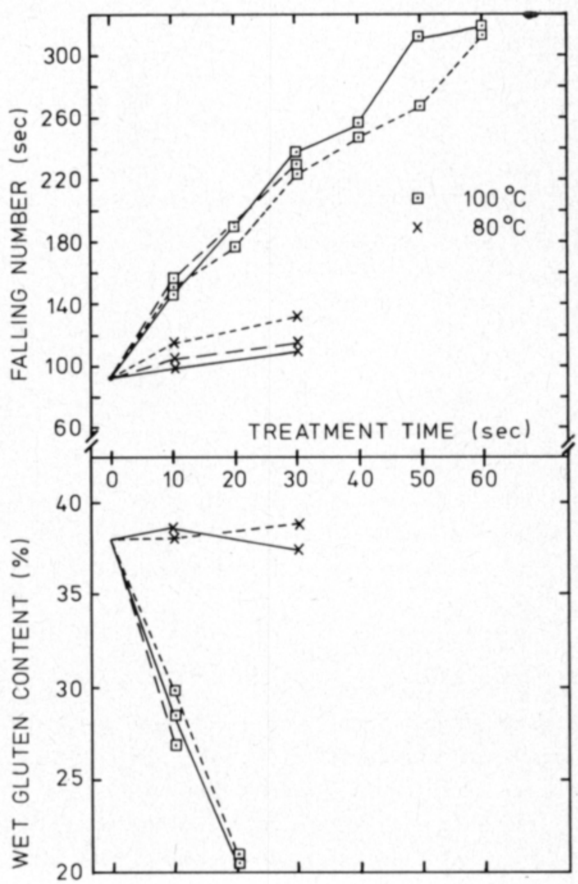

FIG. 1. Influence of hydrothermal treatment at 80 and 100° C on the falling number value and the wet gluten content of sprout -damaged wheat having the temperatures of $+23$ (——), $+5$ (— —) and $-18°$ C (----) at beginning of the processing.

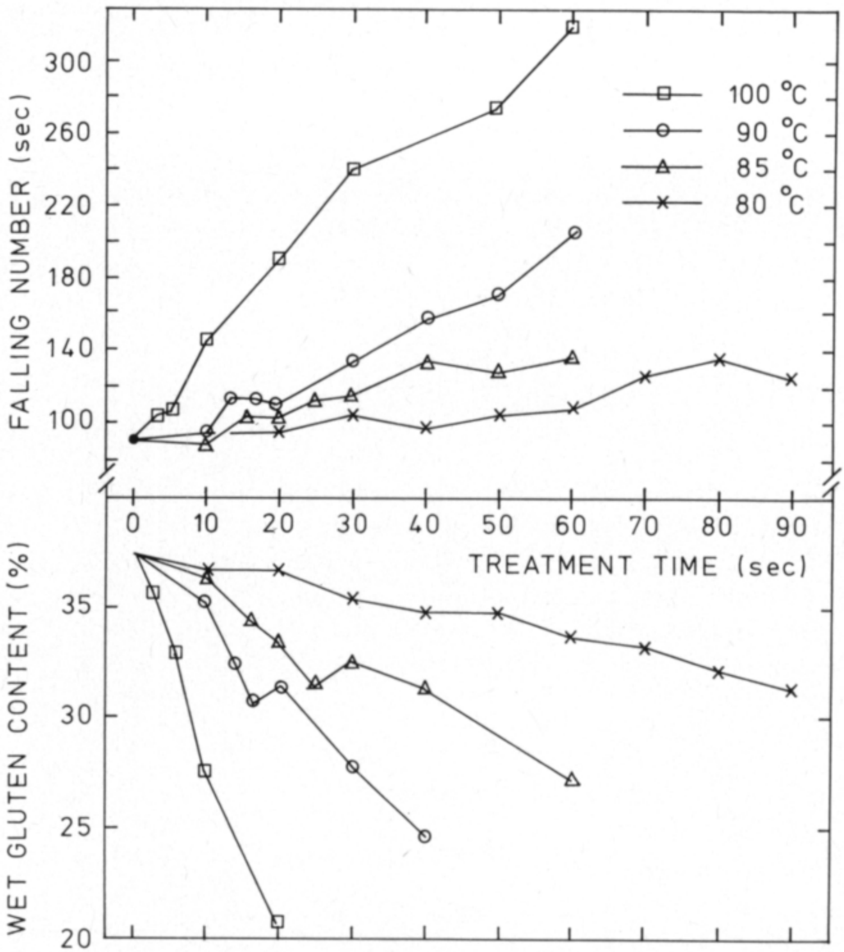

Fig. 2. Influence of hydrothermal treatment at four temperatures on the falling number value and the wet gluten content of sprout- damaged wheat with the initial falling number 91.

no distinct differences in the falling number values and the gluten contents when the temperature of the unprocessed material varied. For example, a 10 sec heat treatment at 100° C raised the falling number from 91 to 144, 148 and 146 when the temperature of the the test materialswere +23, +5 and −18° C, respectively. The gluten of all these samples was seriously heat-damaged. From here on the grain used was of room temperature at the beginning of the processing.

Screening tests

The effect of each heat treatment was analyzed by determining the falling number and the gluten content. The results of these tests are shown in Figs. 2 and 3 for the two wheat lots with different initial falling numbers.

The higher the temperature of the water was, the more rapidly the falling number value of the wheat samples rose and the gluten content decreased.

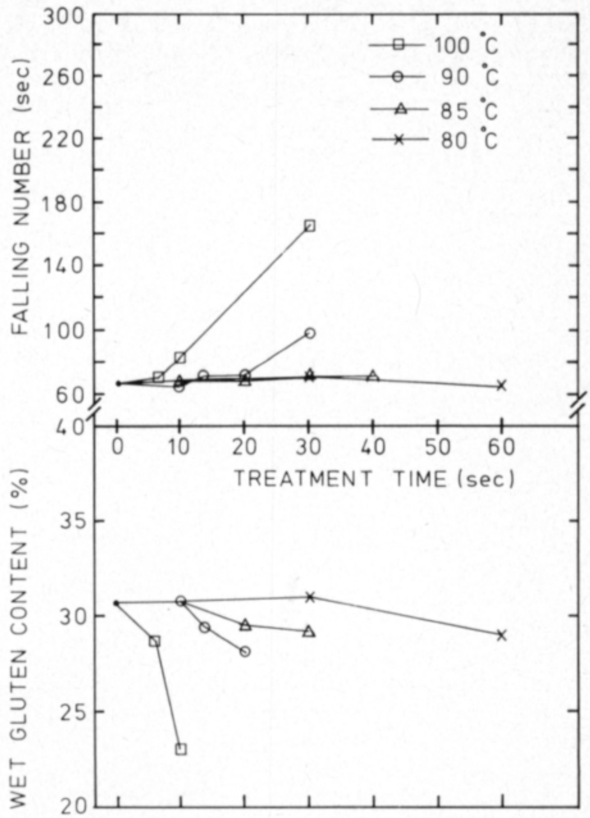

Fig. 3. Influence of hydrothermal treatment at four temperatures on the falling number value and the wet gluten content of sprout-damaged wheat with the initial falling number 65.

The most rapid increases in the falling number were seen at 100° C in both wheat lots. At 80 and 85° C the increases in the lot with the initial falling number of 65 were modest; though the other lot also showed some tendency to increase. Similar treatment of the two lots caused a greater rise in the falling number of the lot having the higher initial falling number. For example, heat treatments at 85, 90 and 100° C for 40, 30 and 10 sec respectively raised the initial falling number from 91 to 136, 133 and 144. The same treatments raised the falling number of the other lot from 65 to 71, 98 and 80.

At the washing out of gluten, heat damages were observable as the treatment became more severe. The gluten concentration decreased, the gluten lost its elasticity, and it became difficult to wash out. On the basis of the subjective results of the gluten quality a tabular statement of the »critical treatments» has been made and is presented in Table 1. The critical treatment was the shortest treatment that at the stated temperature caused disintegration of the gluten at washing. The critical treatments dropped the gluten concentration by 4.4—5.3 percentage units in the lot having the higher falling number. In the other lot this decrease varied between 1.7 and 2.5 percentage units.

The linear regression of the relationship between the results from the falling number and the gluten amount was determined as seen in Table 2. The correlation coefficient was the greater the higher the temperature of the water bath was. The statistical analysis was not made for the other wheat lot because of the much fewer processings performed in this series.

Table 1. Critical heat treatments at four temperatures of sprout-damaged wheat lots and their effect on the falling number value and the wet gluten concentration.

Processing conditions Temperature (° C)	Time (sec)	Falling number (sec)	Wet gluten concentration (%)
0[a]	0	91	37.5
80	70	129	33.1
85	20	104	33.1
90	13	117	32.2
100	6	108	32.9
0[a]	0	65	30.6
80[b]	—	—	—
85	30	70	28.9
90	20	71	28.1
100	6	70	28.6

a) Non-treated samples.
b) The critical treatment was over 60 sec.

Table 2. Correlation between the falling number value and the amount of wet gluten of heat-treated wheat, with the initial falling number 91.

Temperature at processing (° C)	Equation of liner regression ($y = a + bx$)	Coefficient of linear correlation (r)
100° C	$y = 54.7 - 0.191x$	-0.998
90° C	$y = 52.8 - 0.184x$	-0.969
85° C	$y = 53.1 - 0.179x$	-0.905
80° C	$y = 48.1 - 0.126x$	-0.889

The results obtained from both lots showed that at every temperature used the critical treatment of the less sprouted wheat lot caused the falling number to increase and the gluten content to decrease more than in the lot of poorer quality.

Technological experiments

The heat-treated samples that were found to be critically or almost critically treated were more thoroughly examined for their technological properties after milling to flour by farinogram and extensigram determinations and by baking tests.

Milling and ash

The results of milling of the wheat samples are presented in Table 3. The flour yields were very low, especially in the more badly sprouted wheat lot, in which the proportion of mechanically damaged kernels was great. The ash contents of the heat-treated flours were all higher than those of the non-treated lots. The increase varied between 0.04 and 0.18 percentage units in the lot having the falling number 91, and in the other lot the difference was at the most 0.06 percentage units.

Table 3. Milling data of heat-treated sprout-damaged wheat samples.

Processing conditions (sec/° C)	Flour yield (%)[a]	Shorts (%)[a]	Bran (%)[a]	Ash content (%)[b]
Wheat with initial falling number 91				
0/0[c]	64.1	9.9	26.0	0.53
70/80	66.7	10.1	23.2	0.71
20/85	67.1	9.2	23.7	0.57
13/90	66.1	9.0	24.9	0.58
6/100	64.4	9.6	26.0	0.61
10/100	66.8	9.3	23.9	0.62
Wheat with initial falling number 65				
0/0[c]	62.5	10.6	26.9	0.55
60/80	61.0	9.9	29.1	0.59
20/85	61.1	10.0	28.9	0.57
10/90	60.9	10.7	28.4	0.55
13/90	63.9	10.1	26.0	0.61
20/90	61.6	10.5	27.9	0.58
6/100	62.9	9.8	27.3	0.57
10/100	63.8	9.0	27.2	0.61

a) Yield based on total milled material.
b) Calculated on dry basis.
c) Non-treated samples.

Farinogram

The results interpreted from the farinogram curves are shown in Table 4. The water absorption of the flours varied at the most by 1.4 % in spite of difference in processing condition. The initial dough development times of the two lots were 2.0 and 2.5 min. The maximum changes in this value were 0.5 min when the samples were critically treated.

The other interpreted farinogram values indicated deterioration of the mixing properties as a consequence of the critical heat treatments The heat treatments affected the lot of better initial quality more severely than the similarly treated lot of lower quality. The damages in mixing properties are clearly seen in the decreasing values for stability and in the mechanical tolerance index. The better quality lot had an initial stability value of 5.5 min. This value dropped at every treatment, varying between 3.5 and 2.5 min.

The stability value of the other lot was initially 2.5 min and dropped to 2.0 or 1.5 min. The 20 min drop values increased in both trials moderately but did not exceed 40 B.U. even in the overtreated samples.

Table 4. Farinograph data of heat-treated sprout-damaged samples.

Processing conditions (sec/° C)	Water absorption (%)	Dough development time (min)	Stability (min)	Mechanical tolerance index (B.U.)	Time to breakdown (min)	Twnty minute drop (B.U.)
Wheat with initial falling number 91						
0/0[a]	64.7	2.5	5.5	30	8.0	100
70/80	64.0	3.0	3.0	70	5.5	105
20/85	63.6	3.0	3.5	65	5.5	85
13/90	63.3	2.5	2.5	50	4.0	120
6/100	63.3	2.0	3.0	60	4.5	120
10/100	64.2	2.5	2.5	85	4.5	140
Wheat with intial falling number 65						
0/0[a]	65.2	2.0	2.5	90	4.0	150
60/80	64.7	2.5	1.5	110	4.5	160
20/85	64.2	2.5	2.0	110	3.5	160
10/90	65.7	2.0	2.0	90	4.0	150
13/90	65.7	2.0	2.0	110	3.0	160
20/90	64.2	2.0	1.5	130	3.0	170
6/100	65.2	2.0	2.0	130	3.5	150
10/100	64.2	2.0	1.5	130	3.0	180

a) Non-treated samples.

Table 5. Extensigraph data of heat-treated sprout-damaged wheat samples (fermentation time 135 min).

Processing conditions (sec/° C)	Energy (cm]	Resistence to extension[a)] (B.U.)	Extensibility (mm)	Resistance to extension/ Extensibility (B.U./mm)
Wheat with initial falling number 91				
0/0[b]	131	423	177	2.4
70/80	131	577	132	4.4
20/85	135	660	141	4.7
13/90	128	733	124	5.9
6/100	117	655	126	5.2
10/100	79	650	103	6.3
Wheat with initial falling number 65				
0/0[b]	114	410	176	2.3
60/80	94	710	107	6.6
20/85	92	510	127	4.0
10/90	89	493	131	3.8
13/90	97	497	132	3.8
20/90	91	678	108	6.3
6/100	76	510	126	4.0
10/100	69	437[c]	90	4.9

a) Measured at 5 cm.

b) Non-treated samples.

c) Measured after reaching maximum height.

Extensigram

Table 5 shows the values interpreted from the extensigrams, based on the results obtained at a fermentation time of 135 min. All the performed critical heat treatments affected the shape of the extensigram curve.

According to the gluten determinations the energy values of the better quality wheat lot decreased at the most by 14 cm^2 when critically treated at the chosen temperature and heat duration conditions. Overtreatment at 100° C for 10 sec dropped the energy value from the initial value of 131 cm^2 to 79 cm^2.

All heat treatments of the poorer quality lot had on the whole a more pronounced decreasing effect on the energy value. The decreases were about 20 cm^2 after the same treatments at 80, 85 and 90° C that caused decreases of about 3 cm^2 in the other lot. All the treatments performed at 100° C decreased the energy value by about 40 cm^2 in this lot with initial falling number 65.

The heat treatments caused increases in the value for resistance to extension and decreases in the extensibility value. This changes is clearly illustrated by the increase in the ratio between the resistance to extension and the extensibility from 2.3—2.4 to about or over 4.0. The heat treatments raised the resistance to extension in the better lot to a greater extent, but the extensibility decreased to about the same level in both trials treated in the same way.

Baking tests

The results of the baking tests are collected into Table 6. The doughs made from flours of the less sprouted wheat lot were all somewhat sticky although the appearance of the baked breads was quite satisfactory. The bread volumes

Table 6. Baking characteristics of heat-treated sprout-damaged wheat samples.

Processing conditions (sec/° C)	Bread volume (ml)	Specific volume (ml/g)	Height of breads (mm)	Score[a]	Falling number of wheat (sec)
Wheat with intial falling number 91					
0/0[b]	615	4.11	77	188	91
70/80	570	3.81	70	163	129
20/85	615	4.13	83	174	104
13/90	560	3.71	74	154	117
6/100	605	4.03	77	160	107
10/100	392	2.65	56	110	144
Wheat with initial falling number 65					
0/0[b]	615	4.21	75	78	65
60/80	610	3.96	80	99	66
20/85	570	3.92	77	35	68
10/90	623	4.15	81	78	63
13/90	555	3.66	80	38	71
20/90	532	3.75	75	42	70
6/100	580	3.85	75	62	70
10/100	395	2.69	63	11	80

a) According to Dallman (1969).

b) Non-treated samples.

diminished to somə extent after moderate heating of the wheat. Severe heat reatment at 100° C for 10 sec made the doughs even more sticky and the bread volumes decreased sharply. Also the scoring method used indicated poorer baking properties when the samples were critically treated. The crumb of all the breads was a bit damp and of poor elasticity.

The baking properties of the wheat lot having the initial falling number of 65 were quite poor, as seen from the results of the scoring method. All the doughs were sticky, making the moulding operation rather difficult. In spite of the poor baking properties the bread volumes were quite high. The heat treatments had approximately the same influence on the bread volume and the specific volume as in the trial with the better quality wheat. The crumb of all the breads was damp, showed very little elasticity, and the mouthfeel of the breads was doughy. During baking a dense bottom layer formed in the breads with the exception of those with a specific volume above 4.0.

Discussion

The aim of the hydrothermal treatment used was to restrict the penetrating heat to the α-amylase-rich outer layers of the kernels The method of proscessing in hot water and immediate chilling in cold water was chosen because it was the easiest way to ensure that every kernel was exposed to similar and uniform processing conditions. A momentary effective chilling process was of great importance in order to stop the heat from penetrating into the protein rich inner endosperm. According to information from the literature the processings at temperatures as high as above 80° C had to be very short and this made the treatment more complicated to perform.

The results of the present experiments indicated that by the processing method used it was not possible to suppress the excess of α-amylase activity determined by the falling number without denaturing the gluten-forming proteins of the inner endosperm. During immersion of the grain in hot water the heat penetrated to the endosperm although the initial temperature of the material in some experiments was −18° C. According to Schäfer (1954) the temperature difference between the surface layers and the endosperm is smoothed down in less than 30 sec irrespective of the kind of heat treatment used. The critical treatments in our experiments lasted at the most 20 sec with the exception of the treatments at 80° C in the lot of better quality wheat, for which the 70 sec treatment was critical. This long duration also caused the greatest increase in the falling number at the critical point. This observation agrees with the results of Schäfer and Altrogge (1960) who found that heating for 2 min impaired the gluten washing process.

At 90 and 100° C we found the gluten heat-damaged already in 13 and 6 sec in the better quality wheat; in the other lot these durations were 20 and 6 sec. Thə heat damage occurred very rapidly, especially at 100° C, considering that Cleve and Hoffman (1952) showed by thermocolour and thermoelement techniques that 4 sec after treatment with steam and air at 95° C the outer layers of the kernel had a temperature of about 70° C. At this time the temperature in the centre of the kernel had risen only a few degrees. After steam conditioning (118—133° C) for 10—20 sec Schäfer (1952) observed heat damages to the gluten at the washing out operation.

The materials used in these experiments were seriously sprout-damaged and it was found that the more extensively sprouted lot needed more severe processing conditions to attain the same increase in the falling number value. The less sprouted wheat may perhaps have had better qualifications for improvement by this hydrothermal treatment. The starchy endosperm in our samples may also have been too greatly eroded by amylase. When conditioning the sprouted wheat it was furthermore observed that this gluten was more thermolabile than the gluten of non-sprouted wheat (Altrogge and Schäfer 1954). This fact also serves to explain the rapid deterioration of the gluten in our experiments. Furthermore, in the seed germination process the gluten is attacked by proteases, which also may lead to the poorer baking properties of the unprocessed material.

Some heat-treated samples selected on the base of the wet gluten determinations were more thoroughly studied for their technological quality. The critically treated samples indicated or already clearly showed deterioration of the baking properties as compared with the unprocessed material. The overtreatments at 100° C totally damaged the baking properties. The resistance to extension and the extensibility were very sensitive to all the performed treatments. Up to a certain level this change is desirable in the conditioning of soft wheat in order to improve bakeability (Schäfer and Altrogge 1960, Bradbury et al. 1960). The changes in our extensigrams were too high for flours of good bakeability according to Aberham (1971). But Schäfer and Altrogge (1960) have pointed out that the most extreme value for the ratio between the resistance to extention and the extensibility can be as high as 4.5 in steam-conditioned sprouted grain. This value was exceeded in four of the five processed samples with the initial falling number of 91. In the other lot the overconditioning occurred specifically in the three treatments giving this value.

The bread volumes of the both lots were fairly high in spite of the serious sprout damage and heat treatment. The appearance of the breads was also good. The sprout damage was observable as stickiness of the dough and dampness of the crumb. The elasticity of the crumb was also poor. These faults caused by excess α-amylase activity in the flour were not diminished by the hydrothermal treatments performed, as the object had been. The results also indicate that the heat inactivation of amylases should be carried out at higher temperatures than the gluten-forming proteins can tolerate without denaturation.

The conclusion may be drawn from the above trials experiments that for food technological purposes such heat inactivation of excess α-amylase activity in sprout-damaged wheat, probably is appropriate only when the swelling properties of the starch fraction are to be utilized and not the functional properties of the proteins as in the case of breadmaking.

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SELOSTUS

Idäntävaurioituneen viljan hydroterminen käsittely. I. Vaikutukset vehnän teknologiseen laatuun.

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Kaksi idäntävaurioitunutta vehnäerää, joiden sakoluvut olivat 91 ja 65, lämpökäsiteltiin upottamalla viljaa 80, 85, 90 ja 100° C veteen tietyksi ajaksi. Lämpökäsittelyä seurasi välittömästi nopea jäähdytys kylmään veteen upottamalla. Käsittelyn tarkoituksena oli vähentää liiallista α-amylaasiaktiivisuutta jyvien ulkokerroksissa. Lämpökäsittelyn jälkeen α-amylaasiaktiivisuus mitattiin määrittämällä sakoluku. Sakoluvun nousu oli sitä suurempi mitä pitempään lämpökäsittely kesti ja mitä korkeampi veden lämpötila oli. 30 sek kestävä käsittely aiheutti sakoluvun nousun 91:stä 105:een 80° C:ssa, 117:ään 85° C:ssä, 133:een 90° C:ssa ja 238:aan 100° C:ssa. Vastaavasti alempaa sakolukutasoa edustavassa vehnäerässä 30 sek käsittely aiheutti sakoluvun nousun 65:sta 69:ään 80° C:ssa, 70:een 85° C:ssa, 98:aan 90° C:ssa ja 163:een 100° C:ssa.

Sakoluvun noustessa lämpökäsiteltyjen vehnäerien kostean sitkon määrä laski. Näillä muutoksilla oli negatiivinen korrelaatio. Sitkon laadussa ilmeni lämpövaurioita, kun kostean sitkon määrä oli laskenut 5 prosenttiyksikköä sakolukuarvoa 91 edustavassa vehnäerässä ja vastaavasti 2 prosenttiyksikköä sakolukuarvoa 65 edustavassa vehnäerässä. Paremmassa vehnäerässä tämä tapahtui 70 sek:ssa 80° C:ssa, 20 sek:ssa 85° C:ssa, 13 sek:ssa 90° C:ssa ja 6 sek:ssa 100° C:ssa. Heikommassa vehnäerässä vastaavat käsittelyn kestoajat olivat 60, 20, 20 ja 6 sekuntia. Näissä käsittelyissä sakoluvut nousivat 91:stä tasolle 104—129 ja 65:stä tasolle 68—71. Nämä tulokset vahvistettiin farinogrammein, ekstensogrammein ja koeleivonnoin. Samat käsittelyolosuhteet vaikuttivat parempaan vehnäerään voimakkaammin kuin suurempaa idäntävaurioitumisen astetta edustavaan vehnäerään.