

The effect of the combination of reducing and oxidising agents on the viscoelastic properties of dough and sensory characteristics of buns

Pavĺina Peĉivov, Vladimr Pavlinek and Jan Hrab Abstract

BACKGROUND: The effects of mixtures of reducing and oxidising agents on the rheological characteristics and quality of wheat flour dough and the sensory characteristics of buns were studied.

RESULTS: In chemical analyses, no differences between control dough and doughs with individual mixtures of additives were found. Rheological measurements showed that increasing addition of L-ascorbic acid + L-tryptophan mixture to the dough increased its tenacity and decreased its extensibility. Increasing addition of L-ascorbic acid + L-threonine mixture also led to an increase in dough tenacity but to a slight increase in dough extensibility. Increasing addition of L-ascorbic acid + inactivated dry yeast mixture to the dough resulted in a decrease in tenacity and an increase in extensibility. Two other additive mixtures, L-ascorbic acid + L-cysteine hydrochloride monohydrate and L-cysteine p.a. + inactivated dry yeast, reduced both the tenacity and extensibility of the dough. In sensory analyses, differences in dryness, pliability, sensation when swallowing, quality and texture of buns with additive mixtures were found in comparison with control buns, but gumminess did not change significantly with increasing amount of additive mixtures.

Keywords: gluten; rheology; sensory analysis; additive

INTRODUCTION

Among cereal flours, only wheat flour can form three-dimensional viscoelastic dough when mixed with water. Characterisation of the rheological properties of dough is effective in predicting its processing behaviour and controlling the quality of food products.¹

Wheat proteins, especially gluten protein and its fractions, are generally recognised as the most important factors governing the viscoelastic properties of flour dough and its breadmaking quality.²⁻⁴ High protein content is often related to good breadmaking quality. However, protein quantity alone cannot explain all variations in breadmaking quality. Other factors such as protein quality are also important.⁵ Wheat quality is determined by high-molecular-weight glutenin subunits (HMW-GS)⁶ and the molecular weight distribution (MWD) of wheat glutenin.⁷ The MWD is determined by the ratios of monomeric/polymeric proteins, HMW-GS/low-molecular-weight glutenin subunits (LMW-GS) and glutenin/gliadin.^{5,7-12} Indeed, the unusual properties of gluten proteins enable wheat flour to be transformed into dough with suitable properties for breadmaking. These properties are unique and cannot even be closely reproduced in dough made from other cereals.¹³

Traditionally, gluten proteins are divided into two roughly equal fractions according to their solubility in alcohol/water solutions of gluten (e.g. 600 mL L⁻¹ ethanol), namely soluble gliadins

and insoluble glutenins. Gliadins are monomeric proteins with a molecular weight of 30-80 kDa and can be further classified into four groups (*a*, *p*, *y* and *it*).^{1,14}

The glutenin fraction comprises aggregated proteins linked by interchain disulfide bonds, whose sizes range from about 5×10^5 to more than 1×10^7 .^{15,16} Glutenins are polymeric proteins composed of LMW-GS and HMW-GS of 12-60 and 60-120 kDa respectively^{1,14} and are among the largest proteins. The actual sizes of the largest glutenin polymers have not yet been accurately determined because of their enormity.¹⁷ Another reason for difficulties in the size determination of glutenins is their poor solubility in conventional buffers.¹³ However, a significant part of glutenin cannot be solubilised without changing its structure. This high insolubility of glutenin explains why, despite considerable efforts over more than a century, relatively few details on the structure

of glutenin are available. What is known, however, is that glutenin is built of glutenin subunits (GS) that are linked via disulfide bonds. These GS can be liberated by reduction or oxidation of the disulfide bonds with reducing or oxidising agents.¹³

As stated above, the functionality of gluten in wheat flour used for breadmaking is strongly determined by the MWD of glutenin, the occurrence of covalent and non-covalent bonds between glutenin molecules and the interactions between glutenin and other flour constituents. The most prominent linkages are disulfide bonds, as they hold together the GS. Hence oxidising and reducing agents that have a strong impact on the dough thiol/disulfide system can affect the polymerisation of GS and thereby change the mechanical and rheological properties of dough.^{13,18} Even very low concentrations of endogenous glutathione drastically weaken dough and increase its extensibility through thiol–disulfide interchange.¹³ Reducing agents such as L-cysteine may be added to weaken the dough structure. L-Cysteine can also be used in combination with oxidants. During kneading, cysteine cleaves disulfide bonds, which facilitates the distribution of gluten protein in dough and improves dough extensibility.¹³ Cysteine addition increases the fluid-like properties of dough: dough hardness, resistance to extension and storage modulus (G') are lower while adhesiveness and extensibility are higher when cysteine is added.^{19,20}

Cysteine reduces disulfide bonds between proteins and weakens the gluten network of dough, thereby decreasing the elastic (solid-like) component of the dough, aiding in dough relaxation and reducing mixing time.²¹

Generally, cysteine addition leads to an increase in water absorption, a reduction in dough development time and a decrease in dough stability. Addition of L-cysteine hydrochloride (1 mL L⁻¹) increases water absorption but decreases dough development time and dough stability; high levels of cysteine addition increase the compressibility, indicating a decrease in crumb softness, whereas low levels of cysteine addition decrease the compressibility, indicating a softer crumb.²¹

Ascorbic acid is widely used as a flour improver in bread products.²² Although itself a reducing agent, ascorbic acid can exert an oxidising effect on dough properties after its oxidation by atmospheric oxygen during kneading and maturing. It is now generally accepted that the actual improving compound is its first relatively stable oxidation product, i.e. dehydroascorbic acid. The oxidation of ascorbic acid to dehydroascorbic acid takes place quickly and is already completed before the end of the mixing stage.²²⁻²⁴ It is able to create bonds and to strengthen the gluten network in dough.

Amino acids such as L-threonine and L-tryptophan are essential amino acids, a minority amount of which are present in wheat flour. Further addition of these amino acids to flour can increase the nutritional value of final bakery products. So far, these amino acids or their mixtures with ascorbic acid have not been added to dough in order to improve its rheological properties and enhance the organoleptic and nutritional qualities of final bakery products. Their effect on the gluten structure of dough and the organoleptic and nutritional qualities of bakery products is almost unknown.

The rheological properties of wheat flour dough are critical for the successful manufacturing of bakery products, because they determine the dough behaviour during mechanical handling and thus affect the quality of the final product.²⁵ Much of the research in bakery processing has been devoted to the testing of fresh dough.^{26,27}

In wheat breadmaking, flour, water, salt, yeast and/or other micro-organisms are mixed into viscoelastic dough. During dough

mixing, gluten proteins are transformed into a continuous cohesive viscoelastic gluten protein network.^{13,28} During dough fermentation, further changes in the gluten protein network are evident from the observation that gluten proteins become less extractable again.^{29,30} During dough fermenting, the gluten protein network plays a major role in retaining the carbon dioxide produced during fermentation and during the initial stages of baking. Gas retention properties in turn determine the loaf volume and crumb structure of the resulting bread.¹³

During baking, dramatic changes occur in gluten proteins. These are probably a combination of changes in protein surface hydrophobicity, sulfhydryl-disulfide interchanges and formation of new disulfide crosslinks.³¹⁻³⁴ As a result of these heat-induced changes as well as those of starch, the typical foam structure of baked bread is formed.¹³

The aim of this study was to determine the influence of individual combinations of reducing and oxidising agents on the change in viscoelastic properties of wheat flour dough and also the effect of their addition on modification or improvement in quality of bakery products. Amino acids such as L-threonine and L-tryptophan alone or in combination with other amino acids and L-ascorbic acid are not commonly used to modify quality parameters in the baking industry.

MATERIALS AND METHODS

Materials

Wheat flour

For the assessment, common commercial wheat flour T 530 (quantitative parameters: moisture content, 143 g kg⁻¹; gluten content in dry matter, 364 g kg⁻¹; falling number, 339 s) provided by Penam s.r.o. (Kroměříž, Czech Republic) was used.

Additives

Five different combinations of reducing and oxidising agents were selected. The reducing agents used were L-cysteine p.a. (Merck KGaA, Darmstadt, Germany), L-cysteine hydrochloride monohydrate (Ireks GmbH, Eppelborn, Germany), inactivated dry yeast (Ireks GmbH) and L-ascorbic acid (Merck KGaA). The oxidising agents used were L-threonine (Merck KGaA) and L-tryptophan (Merck KGaA).

The first four mixtures comprised wheat flour, L-ascorbic acid (AsA) and a selected additive, either L-tryptophan (Try), L-threonine (Thr), inactivated dry yeast (IDY) or L-cysteine hydrochloride monohydrate (CYS), while the fifth mixture comprised wheat flour, L-cysteine p.a. (Cys) and IDY.

The composition of and amount of additives in individual mixtures are given in Table 1.

Methods

Chemical analysis

Each sample was characterised by dry matter content and pH. Dry matter content was determined according to ISO 560 116-3 (1995). Model dough pH was measured three times using a pH meter with a glass electrode.

Rheological measurement and characteristics The rheological characteristics of wheat flour dough were measured using a Chopin AlveoConsistograph (Tripette & Renaud, France) according to ISO 5530-4 (2002) and ICC Method No. 171

Table 1. Composition of individual mixtures

Group	Mixture of additives ^a	Amount of additives in mixture (g kg ⁻¹)	
		AsA	Try
I	AsA + TryI	1.0	2.0
	AsA + TryII	1.0	3.0
	AsA + TryIII	1.0	4.0
II	AsA + ThrI	1.0	2.0
	AsA + ThrII	1.0	3.0
	AsA + ThrIII	1.0	4.0
III	AsA + IDYI	1.0	2.0
	AsA + IDYII	1.0	3.0
	AsA + IDYIII	1.0	4.0
IV	AsA + CYSI	1.0	0.2
	AsA + CYSII	1.0	0.5
	AsA + CYSIII	1.0	0.6
V	Cys + IDYI	0.1	1.0
	Cys + IDYII	0.1	2.0
	Cys + IDYIII	0.1	3.0

^a AsA, L-ascorbic acid; Try, L-tryptophan; Thr, L-threonine; IDY, inactivated dry yeast; CYS, L-cysteine hydrochloride monohydrate; Cys, L-cysteine p.a.; I, lowest amount of individual amino acid; II, medium amount of individual amino acid; III, highest amount of individual amino acid.

(2008). Breadmaking quality was evaluated using the following parameters: tenacity (*P*, mm), taken as the height of the curve, which measures the initial resistance to extension; extensibility (*L*, mm), taken as the length of the curve; configuration ratio (*P/L*), which indicates the balance of viscoelastic components; dough swelling (*G*, cm³); deformation energy (*W*, J), which indicates dough strength.

The consistograph parameters evaluated were as follows: *PrMax* (mbar), maximum pressure; *TPrMax* (s), time to reach maximum pressure; *Tol* (s) (tolerance, stability), time when pressure is higher than *PrMax* minus 20%; *D250* (mbar), drop in pressure at 250 s from *PrMax* minus 20%; *D450* (mbar), drop in pressure at 450 s from *PrMax* minus 20%.

Baking

The doughs were prepared from 250 g flour with 130gkg⁻¹ water, 4.5 g kg⁻¹ salt, 10gkg⁻¹ yeast, 10gkg⁻¹ margarine and the corresponding amount of mixture (groups I-V) added. The ingredients were mixed in a spiral stirring machine (HLM-HLM-120, A 1 Kuchyně s.r.o., Plzeň, Czech Republic) for 5.5 min, left to stand for 10 min, kneaded and left to stand for a further 10 min. The doughs were then cut into separate pieces in the shape of a bun using a dough divider (HLM-NFK-30, Gastroform s.r.o., Brno, Czech Republic). The pieces were put on a baking tray and left to rise for 30 min at a temperature of 35 °C and a relative humidity of 68%. They were then baked for 10 min at a temperature of 250 °C.

Sensory analysis

Model bread (in the form of buns) was evaluated by a panel of nine assessors (experts from Ireks Enzyma s.r.o., Brno, Czech Republic) trained according to ISO 8586-2 (1994). The

Table 2. Values of dry matter content in individual mixtures of additives

Group	Mixtures of additives ^a	Dry matter content (g kg ⁻¹)	
		Minimum	Maximum
I	AsA + TryI-III	397.9	402.5
II	AsA + ThrI-III	397.5	407.4
III	AsA + IDYI-III	396.2	399.0
IV	AsA + CYSI-III	395.4	398.4
V	Cys + IDYI-III	393.1	395.9

^a AsA, L-ascorbic acid; Try, L-tryptophan; Thr, L-threonine; IDY, inactivated dry yeast; CYS, L-cysteine hydrochloride monohydrate; Cys, L-cysteine p.a.; I, lowest amount of individual amino acid; II, medium amount of individual amino acid; III, highest amount of individual amino acid.

Table 3. Values of pH in individual mixtures of additives

Group	Mixtures of additives ^a	pH	
		Minimum	Maximum
I	AsA + TryI-III	5.82	6.14
II	AsA + ThrI-III	5.92	6.05
III	AsA + IDYI-III	6.00	6.17
IV	AsA + CYSI-III	5.96	6.01
V	Cys + IDYI-III	5.97	6.02

^a AsA, L-ascorbic acid; Try, L-tryptophan; Thr, L-threonine; IDY, inactivated dry yeast; CYS, L-cysteine hydrochloride monohydrate; Cys, L-cysteine p.a.; I, lowest amount of individual amino acid; II, medium amount of individual amino acid; III, highest amount of individual amino acid.

evaluation was performed in a sensory laboratory equipped in accordance with ISO 8589 (1988). The samples of buns were coded and served at room temperature (22 ± 2 °C). A five-point hedonic scale was used for the assessment of dryness, gumminess, pliability, sensation when swallowing, quality and texture.

Statistical analysis

The results of basic chemical analysis were statistically evaluated. The results of sensory analysis were statistically evaluated by means of non-parametric analysis of variance (Kruskal-Wallis test), Friedman test or Wilcoxon test.³⁵ Differences among comparisons had to achieve *P* < 0.05 to show significance.

RESULTS AND DISCUSSION

Chemical analysis

The results obtained by basic chemical analysis showed insignificant differences (*P* > 0.05) in pH and dry matter content among samples with mixtures of additives (groups I-V), as shown in Tables 2 and 3.

Dry matter content in the control dough (CD) was 393.9 g kg⁻¹ and its pH was 6.00.

Table 4. Alveographic characteristics of doughs investigated

Group of mixture ^a (g kg ⁻¹)	Alveographic characteristics ^b				
	<i>P</i> (mm)	<i>L</i> (mm)	<i>P/L</i>	<i>G</i> (cm ³)	<i>W</i> (10 ⁻⁴ J)
None (CD)	95	89	1.06	21.0	287
Group I (AsA + Tryl-III)					
1.0 + 2.0	198	48	4.15	15.4	407
1.0 + 3.0	200	41	4.86	14.3	360
1.0 + 4.0	204	40	5.04	14.2	359
Group II (AsA + Thrl-III)					
1.0 + 2.0	198	46	4.30	15.1	396
1.0 + 3.0	202	44	4.61	14.8	388
1.0 + 4.0	201	47	4.32	15.2	408
Group III (AsA + IDYI-III)					
1.0 + 2.0	225	38	5.86	13.8	382
1.0 + 3.0	231	38	6.14	13.7	391
1.0 + 4.0	212	49	4.36	15.5	440
Group IV (AsA + CYSI-III)					
1.0 + 0.2	114	63	1.80	17.7	220
1.0 + 0.5	90	40	2.22	14.1	110
1.0 + 0.6	99	23	4.26	10.7	95
Group V (Cys + IDYI-III)					
0.1 + 1.0	127	61	2.09	17.4	239
0.1 + 2.0	131	60	2.17	17.3	249
0.1 + 3.0	121	54	2.24	16.4	210

^a CD, control dough; AsA, L-ascorbic acid; Tryl, L-tryptophan; Thrl, L-threonine; IDY, inactivated dry yeast; CYS, L-cysteine hydrochloride monohydrate; Cys, L-cysteine p.a.; I, lowest amount of individual amino acid; II, medium amount of individual amino acid; III, highest amount of individual amino acid.
^b *P*, tenacity; *L*, extensibility; *P/L*, configuration ratio; *G*, dough swelling; *W*, deformation energy.

Table 5. Consistographic characteristics of doughs investigated

Group of mixture ^a (g kg ⁻¹)	Consistographic characteristics ^b				
	<i>PrMax</i> (mbar)	<i>TPrMax</i> (s)	<i>Tol</i> (s)	<i>D250</i> (mbar)	<i>D450</i> (mbar)
None (CD)	2237	173	241	197	742
Group I (AsA + Tryl-III)					
1.0 + 2.0	2285	146	304	150	614
1.0 + 3.0	2215	178	296	106	540
1.0 + 4.0	2101	184	287	95	587
Group II (AsA + Thrl-III)					
1.0 + 2.0	2306	156	322	190	602
1.0 + 3.0	2198	188	326	51	536
1.0 + 4.0	2272	149	302	181	633
Group III (AsA + IDYI-III)					
1.0 + 2.0	2150	196	296	61	544
1.0 + 3.0	2167	176	317	87	557
1.0 + 4.0	2284	206	301	52	528
Group IV (AsA + CYSI-III)					
1.0 + 0.2	2104	100	114	1134	1470
1.0 + 0.5	2291	90	96	1665	1957
1.0 + 0.6	2218	81	90	1723	1980
Group V (Cys + IDYI-III)					
0.1 + 1.0	2188	117	144	733	1048
0.1 + 2.0	2172	112	138	799	1082
0.1 + 3.0	2171	113	131	847	1151

^aCD, control dough; AsA, L-ascorbic acid; Tryl, L-tryptophan; Thrl, L-threonine; IDY, inactivated dry yeast; CYS, L-cysteine hydrochloride monohydrate; Cys, L-cysteine p.a.; I, lowest amount of individual amino acid; II, medium amount of individual amino acid; III, highest amount of individual amino acid.

^b *PrMax*, maximum pressure; *TPrMax*, time to reach maximum pressure; *Tol*, time when pressure is higher than *PrMax* minus 20%; *D250*, drop in pressure at 250 s from *PrMax* minus 20%; *D450*, drop in pressure at 450 s from *PrMax* minus 20%.

Rheological analysis

In order to achieve a complete description of the dough quality needed for baking technology, deformation measurement was used, by means of which the influence of combinations of reducing and oxidising agents on the rheological properties of dough was specified.

Tables 4 and 5 summarise the results for all groups of mixtures added to wheat flour. The same additions of individual groups of mixtures of reducing and oxidising agents were used for dough preparation. If the influence of amino acids and L-ascorbic acid on the rheological properties of dough was not apparent in low amounts, higher amounts were applied.

The individual groups of mixtures (groups I-V) were examined. Thanks to these mixtures, the optimal balance between tenacity, extensibility and stability of the dough and its softening could be reached, which was positively reflected in the quality of the buns.

With increasing addition of L-tryptophan (Tryl-III), group I (AsA + Tryl-III) caused a bigger increase in tenacity but also a bigger decrease in extensibility than group II (Table 4). Furthermore, Table 5 shows that after 250 s there was also a decrease in stability but a slower softening of the dough. After 450 s the dough softened in a similar way as it did with the addition of group II.

With increasing addition of L-threonine (Thrl-III), the effect of group II (AsA + Thrl-III) was an increase in tenacity and an uneven decrease in extensibility of the dough (Table 4). Moreover, with increasing addition of this mixture, the dough became less stable

owing to the instability of L-ascorbic acid, as also reflected by the slow but uneven softening of the dough after 250 and 450 s (Table 5).

It is generally known that oxidising agents are suitable additives for weak flours. Thanks to their ability to strengthen the gluten structure, the dough shows great tenacity and elasticity. Stronger oxidising additives form a firmer dough structure and improve the cohesiveness of dough, especially when weak flours are used.

With increasing addition of inactivated dry yeast (IDYI-III), group III (AsA + IDYI-III) caused an increase in dough tenacity and also a slow increase in extensibility, which was also higher in comparison with groups I and II (Table 4). Moreover, Table 5 shows that with increasing addition of group III the dough became more stable and, compared with groups I and II, softened more slowly after both 250 and 450 s.

With increasing addition of L-cysteine hydrochloride monohydrate (CYSI-III), group IV (AsA + CYSI-III) caused a decrease in both tenacity and extensibility owing to the reducing effects of L-cysteine hydrochloride monohydrate (Table 4). Our results are in agreement with those of Angioloni and Rosa¹⁹ and Miller and Hosney.²⁰ Furthermore, there was a decrease in dough stability and its fast softening (Table 5). Our results are in partial agreement with those of Elkhalfia and El-Tinay.²¹ This effect is caused by the ability of cysteine to break disulfide bridges and damage

Table 6. Results of sensory analysis of tested buns with additive mixtures from groups I–V

Group	Amount of mixture added (g kg ⁻¹)	Sensory evaluation (median) ^{a,b}					
		Dryness	Gumminess	Pliability	Sensation when swallowing	Quality	Texture
I	None	3a	4a	3ab	3a	3a	3a
	1.0 + 2.0	3a	3a	2a	3a	2a	3a
	1.0 + 3.0	3a	2a	3ab	3a	3a	3a
	1.0 + 4.0	3a	3a	4b	2a	2a	2a
II	None	2a	3a	4a	3a	4a	4a
	1.0 + 2.0	3b	3a	3b	3a	3a	3a
	1.0 + 3.0	3ab	3a	3ab	3a	3a	3a
	1.0 + 4.0	3ab	3a	3ab	3a	4a	4a
III	None	2a	2a	4a	4a	4a	4a
	1.0 + 2.0	3ab	3a	4ab	3ab	3ab	4ab
	1.0 + 3.0	3ab	3a	2cb	3b	3b	3ab
	1.0 + 4.0	4b	4a	2c	2b	2b	2b
IV	None	3a	3a	3ab	3ab	3ab	3ab
	1.0 + 0.2	3a	3a	3a	2a	2a	2a
	1.0 + 0.5	2a	3a	4ab	4b	4ab	4b
	1.0 + 0.6	2a	3a	4b	4b	4b	4b
V	None	2a	3a	4a	4a	2a	3a
	0.1 + 1.0	3ab	3a	4a	3a	3a	3a
	0.1 + 2.0	3ab	3a	3a	3a	4a	4a
	0.1 + 3.0	3b	3a	2a	3a	4a	4a

^a The following hedonic scales were used. Dryness: 1 = very dry to 5 = very damp. Gumminess: 1 = very high to 5 = hardly noticeable. Pliability: 1 = very high to 5 = very low. Sensation (when swallowing a bite): 1 = pleasant to 5 = bad. Quality: 1 = excellent to 5 = very bad, unacceptable. Texture: 1 = excellent to 5 = very bad, unacceptable.

^b Median values with the same letter in a column are not significantly different ($P > 0.05$); each group was evaluated separately.

the gluten structure, which leads to an increase in pliability and stickiness of the dough, thus making it less cohesive and more difficult to process. L-Cysteine hydrochloride monohydrate is a strong reducing agent and thus should be added to dough in small amount. It is suitable for the preparation of strong flours.

With increasing addition of inactivated dry yeast (IDYI–III), group V (Cys + IDYI–III) caused a slower decrease in tenacity and extensibility of the dough (Table 4). Moreover, there was a slower decrease in dough stability but faster softening, especially after 450 s (Table 5). Our results are partially consistent with those of Joye *et al.*²²

Sensory analysis of buns with mixtures from groups I–V

The results obtained by sensory analysis showed that the gumminess of all buns did not change significantly with increasing amount of mixtures from all groups ($P > 0.05$) (Table 6). Table 6 also shows that dryness decreased in the buns of group II (AsA + ThrI), group III (AsA + IDYIII) and group V (Cys + IDYIII) in comparison with the control (CD) buns. The biggest decrease in dryness occurred in AsA + IDYIII followed by AsA + CYSII compared with AsA + CYSI ($P < 0.05$).

The expert assessors noticed a decrease in pliability of the buns with AsA + TryIII compared with those with AsA + TryI. On the other hand, an increase in pliability compared with the CD buns was observed in the buns with AsA + ThrI followed by those with AsA + IDYII. Pliability also increased in the buns with AsA + IDYIII compared with those with AsA + IDYI ($P < 0.05$).

A better sensation when swallowing was observed in the buns with AsA + IDYII,III compared with the CD buns. On the

other hand, a worse sensation when swallowing occurred in the buns with AsA + CYSII,III compared with those with AsA + CYSI ($P < 0.05$).

According to the expert assessors, the buns with AsA + IDYII,III were of better quality than the CD buns. On the other hand, worse quality was observed in the buns with AsA + CYSIII compared with the CD buns and also in the buns with AsA + CYSII,III compared with those with AsA + CYSI ($P < 0.05$).

Texture improved in the buns with Cys + IDYIII compared with the CD buns. On the other hand, it deteriorated in the buns with AsA + CYSIII compared with the CD buns and also in the buns with AsA + CYSII,III compared with those with AsA + CYSI ($P < 0.05$).

However, no significant differences in dryness, sensation when swallowing, quality, texture and gumminess were observed between the CD buns and the buns with AsA + ThrI–III. Moreover, no significant differences in dryness and gumminess were found between the CD buns and the buns with AsA + CYSI–III. Also, no significant differences in pliability, sensation when swallowing, quality, texture and gumminess ($P > 0.05$) were found between the CD buns and the buns with Cys + IDYI–III.

CONCLUSIONS

The effects of the combination of reducing and oxidising agents on the viscoelastic properties of dough and the sensory characteristics of buns were investigated.

Chemical analyses of the dough samples revealed that the pH did not change with increasing addition of the combination of mixtures to the dough. With respect to the comparison of rheological changes, it cannot be said that the change in pH

caused by the addition of mixtures of reducing/oxidising agents influences the binding capacity of the dough. It is solely the influence of the mixtures of reducing/oxidising agents caused by their chemical characteristics that leads either to an increased capability to create hydrogen bridges (oxidation effect) or other weak binding interactions or, on the contrary, to blocking or reducing the formation of thiol bridges (reducing effect). Moreover, there was no change in dry matter content compared with the control dough. Thus the combination of mixtures did not affect the moistness of the dough either.

According to the rheological results, within groups I-III (AsA + Tryl-III, AsA+Thrl-III and AsA + IDYI-III respectively), group I (AsA + Tryl-111) and group III (AsA + IDYI-III) can be recommended thanks to slower softening after 250 and 450 s. Otherwise, the effects of the above-mentioned mixtures are generally comparable and they can be recommended as suitable mixtures of additives to 'weak' flours (flour with damaged gluten). In general, these mixtures are able to strengthen the gluten network and thus increase dough elasticity. Such bakery products show a greater volume and better porosity.

In groups IV and V (AsA + CYSI-111 and Cys + IDYI-III respectively) at the additions given, group V (Cys 4- IDYI-III) proved to be better thanks to the fact that it provides better tenacity, elasticity and stability of the dough. Unlike groups I-III, these mixtures are able to weaken the gluten network and thus increase dough extensibility and decrease its elasticity, which leads to a smooth course of fermentation. They are suitable for flours with 'solid' gluten (flour with quality gluten).

The sensory analysis revealed a significant decrease in dryness in the buns with AsA + Thrl, AsA + IDYIII and Cys + IDYIII compared with the control (CD) buns. The most significant decrease in dryness occurred in the buns with AsA + IDYIII. In comparison with the CD buns, an increase in pliability occurred in the buns with AsA + Thrl and AsA + IDYII. Compared with the CD buns, the sensation when swallowing improved in the buns with AsA + IDYIII. The buns with AsA + IDYII,III showed a better quality than the CD buns. The texture improved in the buns with Cys + IDYIII in comparison with the CD buns.

On the other hand, the buns with AsA + CYSIII showed a significantly worse quality and texture compared with the control CD buns. This combination of additives leads to considerable destruction of the gluten structure due to the effect of L-cysteine hydrochloride monohydrate. Therefore this mixture is more suitable to add to strong flours.

The gumminess of all buns did not change significantly with increasing amount of mixtures.

Also, group I (AsA + Tryl-III) and group II (AsA + Thrl-III) are recommended to be added in small or medium amounts, because large amounts, i.e. AsA + TrylIII and AsA + Thrill, have undesirable effects on the gluten structure, as they lead to great strengthening of this structure, which is not suitable in flours with good quality gluten. However, it can be used in flours with poor gluten structure (bad quality gluten), where such strengthening is desirable.

Therefore the combination of instrumental methods and sensory analysis is useful for qualitative evaluation of the final bakery products obtained with mixtures of reducing and oxidising additives.

These mixtures were added to improve the viscoelastic properties of wheat flour dough, which leads to good quality bakery products. Moreover, they are also important from the nutritional point of view, because there are only small amounts of essential amino acids (mainly L-threonine and L-tryptophan) in

wheat flour and thus their addition to wheat flour increases the nutritional value of the final bakery product (buns).

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