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Incorporation of dairy ingredients into wheat bread: effects on dough rheology and bread quality

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Abstract Dairy ingredients are used in breadmaking for their nutritional benefits and functional properties. The effects of the traditionally-used whole and skimmed milk powder, sodium caseinate, casein hydrolysate and three whey protein concentrates on dough rheology and bread quality were studied. Whole and skimmed milk powders improved sensory characteristics. Sodium caseinate and hydrolysed casein displayed beneficial functional properties in breadmaking including low proof time, high volume and low firmness. Both ingredients increased dough height measured with the rheofermentometer. Bread with 2% or 4% sodium caseinate added was rated highly in sensory evaluation. Incorporation of whey protein concentrates generally increased proof time, decreased loaf volume and decreased dough height measured with the rheofermentometer.

Key words Wheat · Dough · Bread · Sodium caseinate · Casein hydrolysate

Introduction

Dairy ingredients are incorporated into bread for their nutritional and functional benefits. Nutritional benefits include increasing calcium content, increasing protein content and supplementation of the essential amino acids lysine, methionine and tryptophan. Functional benefits of dairy ingredient incorporation include improvement of dough handling properties and bread quality (flavour, crust colour, toasting characteristics, crumb structure and crumb texture). These functional benefits are as a result of the effects of milk fat and protein. Dairy ingredients vary widely in overall composition and in the extent of denaturation in the case of dairy protein powders, making them difficult to categorise [1, 2].

Whole milk powder (WMP) and skimmed milk powder (SMP) have traditionally been used in baking but are being replaced by less expensive dairy ingredients e.g. whey powder and milk proteins with particular functional properties. Whey proteins are primarily used in cereal products to improve nutritional properties. Whey protein concentrate (WPC) is considered to be the most efficient wheat protein supplement [3, 4] and also increases calcium content when added to cereal products [5]. Whey proteins exert negative effects on bread quality, by depressing loaf volume and increasing crumb firmness. However, modification of the extent of protein denaturation by heat treatment [6, 7] or the use of high hydrostatic pressure [8] can counteract these effects.

Acid casein has drastic effects on bread volume, which cannot be eliminated by heat treatment [9]. Sodium caseinate (SC), which has excellent surfactant properties, attributed to the amphiphilic nature of the protein, is used as an emulsifier, thickener and foaming agent and is known to increase water absorption in flour systems [2]. There is little published, however, on the effects of SC in breadmaking. This is probably due to the fact that caseinates are quite expensive. However they already have applications in value-added products such as frozen dough.

Milk proteins, in particular caseins and caseinates are employed in food formulations for their contribution to enhanced functionality including emulsifying, foaming and whipping properties [10, 11]. Enzymatically hydrolysed milk proteins have also been exploited to give enhanced nutritional properties in food formulations and to achieve desirable functional properties.

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For example, SC hydrolysates produced using a *Bacillus* proteinase complex exhibited enhanced emulsion activity at low pH, increased foam expansion and decreased foam drainage at high pH, compared to the unhydrolysed control [12]. In the development of hydrolysates for incorporation into food formulations, key variables including taste, functionality and allergenicity require precise control to ensure optimal performance of the hydrolysate in the final product.

In this study, we investigated the effects of dairy ingredients on bread quality and dough rheology using the farinograph, extensograph and rheofermentometer. The dairy ingredients evaluated included commercial WMP and SMP, which are the traditionally-used dairy ingredients in breadmaking, SC, hydrolysed acid casein and three WPCs.

Materials and methods

Ingredients. The flour used was commercial wheat flour (Odlum, Dublin, Ireland) which contained 12.7% protein (moisture basis). Compressed yeast was used (DCL Yeast Clackmannanshire, UK) and baking margarine was obtained from Stork, Van den Bergh, Crawley, UK.

In Table 1 the composition of dairy ingredients used is shown. WMP and SMP were commercial products obtained from the Irish Dairy Board, Dublin, Ireland. SC was manufactured in University College Cork, Ireland and contained 87% protein. Casein hydrolysate (CH) with a protein content of 79% was manufactured in Teagasc, Dairy Products Research Centre, Moorepark, Ireland. WPCs included WPC1 containing 75% protein (Carbery, Ballineen,Ireland), and WPC2 containing 79% protein (Teagasc). WPC3 containing 79% protein was a commercial product modified to improve its gelation properties, obtained from New Zealand Dairy Ingredients. The protein content of dairy ingredients was determined using a Kjeldahl method [13].

Preparation of CH. Acid casein (Dairygold, Mitchelstown, Ireland) was used as the substrate for enzymatic hydrolysis using a fungal protease/peptidase complex produced from *Aspergillus oryzae*, with optimum pH in the range 7–8 (Novo Nordisk, Bagsvaerd, Denmark). The acid casein (200 g) was dispersed in 1800 ml water and the pH was increased to 7.0, with 4 N NaOH, yielding 8% (w/v) protein in the vessel, which was subsequently hydrolysed with the protease/peptidase complex at 50 °C in a thermostatted reaction vessel (Braun, Biotech., Melsungen, Germany), at pH 7.0. Throughout enzymatic hydrolysis, pH was maintained at a constant using a pH stat (Metrohm, Herisau, Switzerland), by the addition of 4 M NaOH. The degree of hydrolysis, defined as the percentage of hydrolysed peptide bonds was calculated from the volume and molarity of NaOH required to maintain constant pH, while the enzyme to substrate ratio was 0.5 on a protein basis and enzyme powder was taken as 100% protein, as supplied. Upon completion of enzymatic hydrolysis, thermal inactivation of the enzyme was achieved by heating the hydrolysate at 80 °C for 20 min. Finally the product was spray-dried. The hydrolysate consisted of an array of peptides with molecular mass, μr less than 1500 D, as confirmed by HPLC, indicating that the hydrolysate was extensively hydrolysed, containing peptides of no longer than 11 residues based on the average μr per residue of 125 D. Gel permeation HPLC, using a TSK G2000 SW column (600 × 7.5 mm, Tosu Hass, Japan) fitted to a Waters (Millipore, Middlesex, UK) HPLC system. Sample preparation and chromatographic conditions have been described previously [12]. A molecular weight calibration was prepared from average retention times of standard proteins and peptides.

Table 1 Composition of dairy ingredients[a]

Ingredient	Protein	Fat	Lactose	Ash	Moisture
WMP	26.3	27.1	37.6	5.8	3.2
SMP	35.3	1.2	53	7.5	3
SC	87	1.6	0.1	3.7	7
CH	79	< 1.0	< 0.2	16	6
WPC1	75	9.1	6.7	2.9	5.8
WPC2	79	7.8	3.9	2.7	6
WPC3	79	4.6	6	4.5	4.2

[a]Mean values of at least two determinations

Farinograph. Doughs containing flour, water and 2% or 4% dairy powder were tested according to the ICC standard method [14]. Each result is the average of four measurements.

Extensograph. Doughs containing flour, water and 2% or 4% milk powder were tested according to the AACC standard method [15]. Each result is the average of six measurements.

Dough formulation. Ingredients included 4% yeast, 2% salt, 1.5% sugar, 3% shortening and 2% or 4% dairy ingredients (all based on percentage of flour weight). Water addition was calculated as farinograph water absorption at 500 Brabender Units (BU) minus 2%.

Rheofermentometer. Gas formation and retention in fermenting doughs were determined using a Rheofermentometer F3 (Chopin, Villeneuve la Garenne, France). Dough was mixed using the farinograph and prepared using the formulation above. Dough (300 g) was placed in the fermentation vat at a temperature of 30 °C for 2.5 h and a weight constraint of 1.5 kg was applied. Each result is the average of three measurements.

Baking tests. A straight dough baking procedure was used. Doughs containing 1 kg flour were mixed in a high-speed mixer (Stephan, Hameln, Germany) for 2 min and rested for 20 min at 30 °C. They were divided into 65 g portions, placed in tins and proofed (30 °C, 85% relative humidity) to a standard proof height, 2.5 cm above the tin. Baking was carried out at 220 °C top oven temperature 200 °C bottom oven temperature for 30 min in a deck oven (MIWE, Arnstein, Germany). The bread loaves were cooled at room temperature. Volume was measured 2 h after baking, using rapeseed displacement. Loaves, which were stored, were packaged in polyethylene bags 3 h after baking and stored at 19 °C.

Bread crumb firmness was evaluated 3 h, 1 day and 2 days after baking using a Texture Analyser TA-XT2i (Stable Micro Systems, Surrey, UK) with a 25 kg load cell. The maximum force required to compress a 25 mm slice by 25% using a 20 mm aluminium cylindrical probe at 1 mm/s was determined as the firmness value.

Bread crumb and crust colour were determined using a Minolta Chromameter (Minolta CR-300, Osaka, Japan). Hunter *L* values, which measure lightness were recorded.

Sensory evaluation involved taste panels 1 day after baking, in which evaluators were asked to rate sensory attributes (flavour, odour and texture) and overall acceptability. The scale for attributes and acceptability was 0, very poor; 1, poor; 2, fair; 3, good; and 4, very good. The taste panel comprised 20 evaluators and the same taste panel carried out evaluations on 2 different days.

Statistical evaluation. Analysis of variance was used to evaluate the data using using the statistical software package SPSS. Tukey's post hoc test was used to detect significant differences at $P < 0.05$.

Results and discussion

Farinograph

Farinograph data are presented in Table 2. WMP (4%) had no effect whilst 4% SMP increased water absorption by over 1%. Addition of SC increased water absorption considerably; 2% SC increased the value by 3% and 4% SC increased water absorption by almost 9%. CH (4%) decreased water absorption by 2%. All three WPCs decreased water absorption by approximately 1%. Levels of 4% WMP, 4% SMP, 4% CH and 4% WPC3 all decreased dough stability, whilst 4% WPC1 and 4% WPC2 both increased stability compared to the control. Interestingly, 2% SC decreased stability whereas 4% SC increased it. Levels of 4% SC, 4% WPC1 and 4% WPC2 decreased the degree of softening whereas 4% CH and 4% WPC3 increased it. After 20 min mixing, 4% WMP, 4% SMP, 2% SC, 4% SC, 4% WPC1 and 4% WPC2 all decreased the degree of softening compared to the control whereas 4% CH and 4% WPC3 increased it.

Extensograph

Figure 1 shows the influence of dairy powders on dough resistance to extension measured at 5 cm extension (R5cm) with the extensograph after 45, 90 and 135 min resting. Doughs with 4% WMP had slightly higher R5cm values ($P<0.05$) compared to the control after 90 min and 135 min. SMP at 4% did not affect R5cm. SC at 2% decreased R5cm by 100 BU after 45 min and by 90 BU after 90 min. After 135 min fermentation, the 2% SC dough had similar R5 cm values to the control. SC at 4% decreased R5cm after 45 min, whereas after 135 min, R5 cm was higher than the control. The 4% CH dough did not show significant differences in R5cm compared to the control. At 45 min fermentation, WPC1 decreased R5 cm whereas WPC2 slightly increased it. At 135 min fermentation both WPC1 and WPC2 doughs had higher R5 cm values than the control. WPC3 decreased R5 cm after 45, 90 and 135 min by 130, 90 and 80 BU respectively.

Table 2 Effects of dairy ingredients on farinograph measurements*. *E10* Degree of softening after 10 min, *E20* degree of softening after 20 min

	Absorption	Stability	E10	E20
Control	62[d]	7[c]	50[c]	115[c]
4% WMP	62[d]	4[e]	45[c]	80[d]
4% SMP	63.3[c]	5.5[d]	45[c]	90[d]
2% SC	65[b]	5[d]	45[c]	85[d]
4% SC	70.8[a]	9[b]	20[d]	85[d]
4% CH	59.8[e]	4[e]	65[b]	135[b]
4% WPC1	61[e]	9[ab]	15[d]	85[d]
4% WPC2	61[e]	9.5[a]	15[d]	80[d]
4% WPC3	61[e]	3.5[f]	105[a]	195[a]

*Data in each column superscripted by the same letter denote mean values that are not significantly different ($P<0.05$)

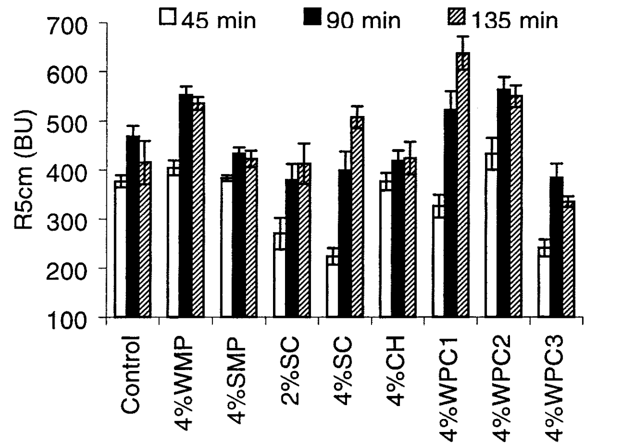

Fig. 1 Effects of dairy ingredients on resistance to extension at 5 cm (*R5cm*) measured with the extensograph. *WMP* Whole milk powder, *SMP* skimmed milk powder, *SC* sodium caseinate, *CH* casein hydrolysate, *WPC* whey protein concentrate

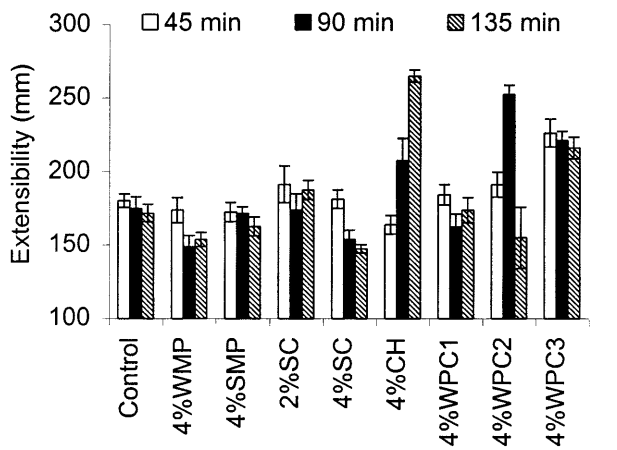

Fig. 2 Effects of dairy ingredients on dough extensibility measured with the extensograph

Extensibility values measured with the extensograph at 45, 90 and 135 min fermentation are shown in Fig. 2. After 45 min, dough with WPC3 had a significantly higher value than the control ($P<0.05$). After 90 min, 4% CH, 4% WPC2 and 4% WPC3 increased extensibility. After 135 min, 4% SC, 4% CH and 4% WPC3 all increased extensibility ($P<0.05$).

Rheofermentometer

Figure 3 shows dough development curves. Doughs with 4% WMP and those with 4% SMP had similar dough development curves to the control and all three doughs had similar height and after 2.5 h fermentation. Levels of 2% SC, 4% SC and 4% CH all significantly

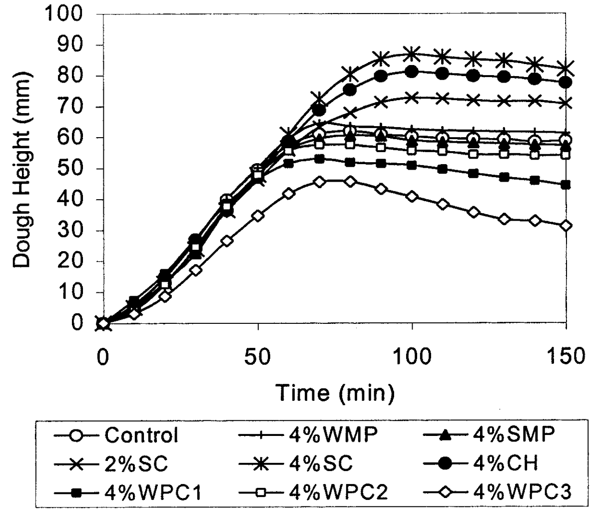

Fig. 3 Dough development curves obtained using the rheofermentometer showing dough height during 2.5 h fermentation at 30 °C and 1.5 kg weight constraint

increased dough height. SC at 2% increased maximum dough height (Hm) and final dough height (H) by 11 mm and 12 mm respectively. SC at 4% increased Hm and H by 25 mm and 23 mm respectively, whilst 4% CH increased Hm and H by 19 mm and 18 mm. All WPC powders depressed dough height; 4% WPC1 and 4% WPC2 decreased Hm and H slightly whereas 4% WPC3 had a considerable effect on dough height, decreasing Hm and H by 17 mm and 31 mm respectively. Dough development measured with the rheofermentometer corresponded very well to baking quality. Doughs with higher values for Hm and H had shorter proof times, larger volumes and low crumb firmness values.

Baking tests and bread evaluation

Figure 4 shows the effects of dairy ingredients on proof time. Formulations with 4% WMP and 4% SMP reached the standard dough height in similar times to the control, whilst 2% SC, 4% SC and 4% CH all decreased proof times. All WPC powders increased proof time and WPC3 gave the largest increase in proof time.

Figure 5 shows the effect of dairy ingredients on specific bread volume. Incorporation of 4% WMP or 4% SMP produced breads with similar specific volumes compared to the control, whilst 2% and 4% SC increased specific volume by 10% and 20% respectively. CH at 4% increased specific volume by 13%. WPC1, WPC2 and WPC3 decreased specific volume by 7, 4 and 9% respectively.

Bread firmness values measured 3 h, 1 day and 2 days after baking with the texture analyser are presented in Fig. 6. Bread with 4% WMP and 4% SMP had

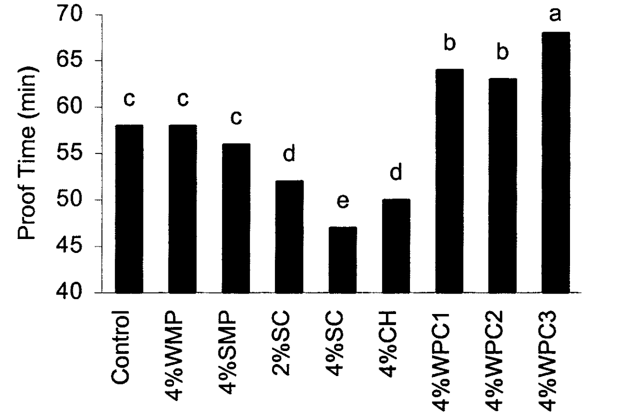

Fig. 4 Effects of dairy ingredients on proof time to reach a standard proof height. Histogram *bars* annotated with the same letter denote mean values that are not significantly different ($P<0.05$)

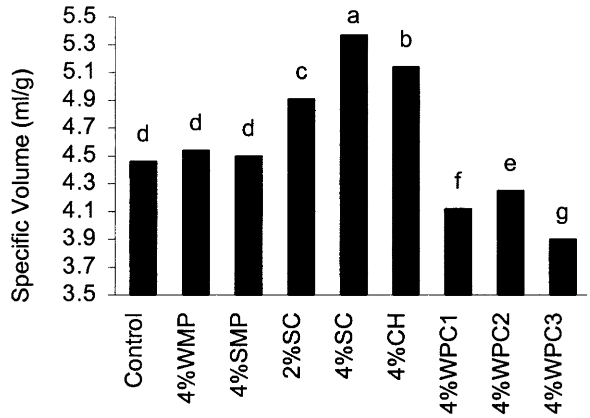

Fig. 5 Specific volume of bread loaves containing dairy powders. Histogram *bars* annotated with the same letter denote mean values that are not significantly different ($P<0.05$)

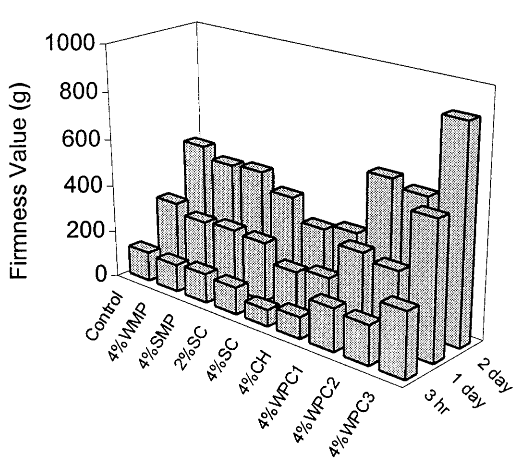

Fig. 6 Effects of dairy ingredients on bread crumb firmness values measured by compression using the texture analyser 3 h, 1 day and 2 days after baking

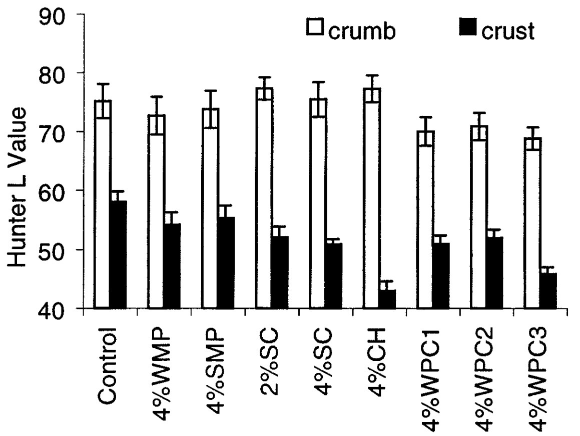

Fig. 7 Effects of incorporating dairy ingredients on Hunter *L* values of bread crumb and crust

similar firmness values to the control. Addition of 2% SC, 4% SC and and 4% CH all decreased crumb firmness; 4% SC produced the softest bread followed by 4% CH. SC at 4% decreased crumb firmness values by 44% after 3 h and 40% after 2 days when compared to the control. Levels of 4% WPC1 and 4% WPC2 increased crumb firmness slightly, but 4% WPC3 had an unacceptable affect on crumb firmness increasing it by 54% and 76% after 3 h and 2 days respectively.

Figure 7 shows Hunter *L* values measured for crumb and crust colours. All three WPC powders had slightly lower *L* values for the crumb than the control ($P<0.05$) and therefore a slightly darker crumb colour. All bread incorporating dairy ingredients, especially CH and WPC3 had lower crust L values than the control ($P<0.05$), indicating darker crust colour.

In Table 3 is shown the results of the sensory evaluation of bread containing dairy powders. Bread with WMP was preferred to the control and scored slightly higher than the control for flavour odour and overall acceptability. Bread with SMP scored higher than the control for flavour. Bread containing 2% and 4% SC scored higher than the control for flavour, odour and for overall acceptability. Bread manufactured with 4% CH produced an undesirable off-flavour and odour and consequently scored poorly in sensory evaluation. Breads with 4% WPC1 and 4% WPC2 scored similarly to the control whereas bread with 4% WPC3 scored poorly.

Table 3 Sensory evaluation of bread made with milk powders Rating scale: 0 very poor, 1 poor, 2 fair, 3 good, 4 very good

	Flavour	Odour	Texture	Acceptability
Control	2.7^{b}	2.7^{b}	2.6^{b}	2.7^{b}
4% WMP	3.6^{a}	3.4^{a}	2.8^{b}	3.5^{a}
4% SMP	3.4^{a}	2.6^{b}	2.6^{b}	2.8^{b}
2% SC	3.5^{a}	2.9^{b}	3.6^{a}	3.5^{a}
4% SC	3.7^{a}	3.2^{ab}	3.7^{a}	3.7^{a}
4% CH	1.3^{c}	1.1^{c}	2.7^{b}	1.5^{c}
4% WPC1	2.9^{b}	2.9^{b}	2.6^{b}	2.7^{b}
4% WPC2	2.8^{b}	2.7^{b}	2.6^{b}	2.6^{b}
4% WPC3	1.4^{c}	1.3^{c}	1.2^{c}	1.2^{d}

*Data in each column superscripted by the same letter denote mean values that are not significantly different ($P<0.05$)

Traditionally-used WMP and SMP showed limited functional properties in bread baked by the straight dough process. WMP improved sensory attributes and crust colour of bread and SMP improved bread flavour and crust colour. However, WMP or SMP did not significantly affect bread characteristics such as loaf volume and crumb firmness.

The addition of 2% or 4% SC had functional benefits in breadmaking; water absorption was increased, proof time and crumb firmness were decreased, loaf volume increased and scores for sensory attributes increased. SC is an expensive ingredient for regular white pan bread, but its use would be feasible in value-added products such as speciality breads, convenience foods and frozen dough.

Acid casein is known to have a negative effect in breadmaking [9]. The CH derived from acid casein, which was extensively hydrolysed, displayed positive effects in breadmaking. It decreased proof time, increased loaf volume and decreased crumb firmness. However, CH produced an off-flavour and odour in bread, which was rated poorly in sensory evaluation. It is well-documented that CHs exhibit a bitter taste [16, 17] which is primarily attributed to the hydrophobic residues of casein. Means of bitterness reduction in CHs have been identified and include the use of exopeptidases [17].

WPC1 and WPC2, typical commercial WPCs both had a slightly negative effect on bread quality. WPC2 performed slightly better than WPC1 even though they were of similar composition. This is probably due to differences in processing as these powders were from two different sources. WPC3 was unsuitable for breadmaking due to its altered gelation properties.

In conclusion, it was demonstrated that SC was very effective as an improver in wheat bread prepared by a straight dough baking process. Enzymatic hydrolysis of acid casein produced an ingredient with beneficial functional properties in breadmaking. In general WPCs had a slight negative effect on bread quality but produced an acceptable product.

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