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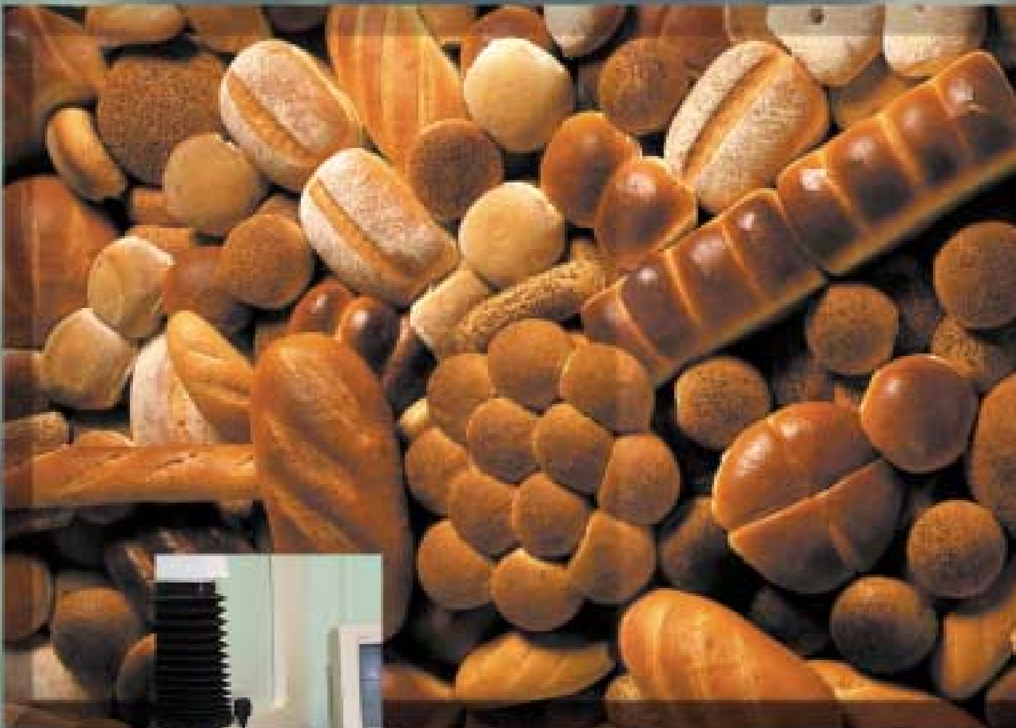
FINAL REPORT

Project RMIS No. 4881

Improving the Quality of Gluten-Free Products



The National Food Centre

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

RESEARCH REPORT NO 67

IMPROVING THE QUALITY OF GLUTEN-FREE PRODUCTS

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SUMMARY

The incidence of coeliac disease or other allergic reactions/intolerances to gluten is increasing, largely due to improved diagnostic procedures and changes in eating habits. The worldwide number of sufferers of coeliac disease has been predicted to increase by a factor of ten over the next number of years, resulting in a growing market for gluten-free cereal-based products. Market research has shown that many of the products currently on sale are of inferior quality. The replacement of gluten presents a major technological challenge, as it is an essential structure-building protein which is necessary for formulating high quality cereal-based goods. Therefore, the production of high quality gluten-free bread is difficult.

The objective was to investigate a range of starch sources (rice, potato), protein and fibre sources (dairy proteins, fish protein, inulin) and hydrocolloids (xanthan gum, konjac gum, hydroxypropylmethylcellulose [HPMC]) which may be used to replace gluten. Two types of bread were developed at The National Food Centre: *(i)* wheat starch-based, and *(ii)* free from wheat starch. These were evaluated by members of the Coeliac Society of Ireland. The project partners in University College Cork developed gluten-free biscuits and pizza bases and a précis of their results is also included in this report.

Outcomes (at The National Food Centre) from the project were:

- Dairy powders with high protein contents (80-90%) produced wheat starch-based gluten-free breads with good crust and crumb characteristics, improved nutritional content and high sensory acceptability scores;
- Fish surimi, in particular blue whiting surimi, has potential as a crust/crumb softener in wheat-free breads. Breads with blue whiting surimi were preferred to a non-surimi-containing control in sensory tests;
- Adding inulin to a wheat-free bread at a level of 4% resulted in increased loaf volumes. The overall appearance of the bread was improved, dietary fibre content was boosted and the breads were acceptable to taste;
- Optimised levels of HPMC and water were calculated for a rice/potato starch-based gluten-free bread formulation. Increasing water content

significantly increased loaf specific volume and height and decreased crumb firmness. HPMC addition lightened crumb colour. Both HPMC and water significantly affected the digital image analysis of the crumb grain.

INTRODUCTION

Coeliac disease is a life-long intolerance to the gliadin fraction of wheat and the prolamins of rye (secalins), barley (hordeins) and possibly oats (avidins). The reaction to gluten ingestion by sufferers of coeliac disease is inflammation of the small intestine leading to the malabsorption of several important nutrients including iron, folic acid, calcium and fat-soluble vitamins. Symptoms associated with coeliac disease include diarrhoea or constipation, anaemia, mouth ulcers, abdominal pain, bloating, fatigue, infertility, neuropsychiatric symptoms (anxiety, depression) and osteoporosis.

Coeliac disease is more common in Ireland than anywhere else in the world. It is particularly prevalent in the West of Ireland. Conservative estimates in Ireland consider that approximately ten thousand people, who regularly feel unwell without ever knowing why, suffer from undiagnosed coeliac disease. The 'iceberg model' (Figure 1) is a common graphic which explains the prevalence of coeliac disease. The tip of the iceberg (A) is formed by patients with overt disease that have been diagnosed by biopsy of the gut, demonstrating a flat mucosa. Below the waterline (B) there is a big group of "silent" cases, which have not been identified. They may remain undiagnosed because the symptoms have not been recognised or linked to coeliac disease. At the bottom of the iceberg (C), there is a small group of patients with latent coeliac disease. These show a normal mucosa while taking gluten, yet still have the potential to develop the disease.

Recent epidemiological studies suggest that there will be a significant increase in the incidence of coeliac disease and gluten intolerances, mainly due to improved diagnostic procedures.

The only effective treatment for coeliac disease is strict adherence to a gluten-free diet throughout the patient's lifetime, which, in time, results in clinical and mucosal recovery. Foods not allowed in a gluten-free diet include: (i) any bread, cereal or other food made with wheat, rye, barley, triticale, dinkel,

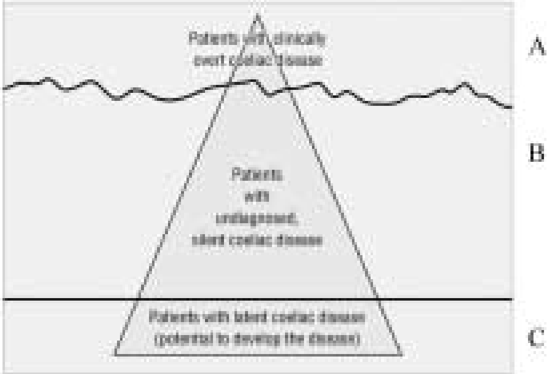


Figure 1: Iceberg model depicting prevalence of coeliac disease (Feighery, 1999)

kamut and oat flour or ingredients, and by-products made from those grains; (ii) processed foods that contain wheat or gluten derivatives, for example thickeners and fillers in hot dogs, salad dressings, canned soups/dried soup mixes, processed cheese, cream sauces; and (iii) medications that use gluten as pill or tablet binders.

Gluten is a proteinaceous material that can be separated from flour when the starch and other minor components of the flour are removed by washing out under running water. The resulting gluten contains approximately 65% water. On a dry matter basis, gluten contains 75-86% protein, the remainder being carbohydrate and lipid, which are held strongly within the gluten-protein matrix (Bloksma and Bushuk, 1998). Gluten contains the protein fractions glutenin and gliadin. The former is a rough, rubbery mass when fully hydrated, while gliadin produces a viscous, fluid mass on hydration. Gluten, therefore, exhibits cohesive, elastic and viscous properties that combine the extremes of the two components. The gluten matrix is a major determinant of the properties of dough (extensibility, resistance to stretch, mixing tolerance, gas holding ability), enclosing the starch granules and fibre fragments.

Gluten removal, especially in bread formulations, results in major technical problems for bakers, yielding a liquid batter rather than a dough (Figure 2), and bread with a crumbling texture, undesirable colour and other quality

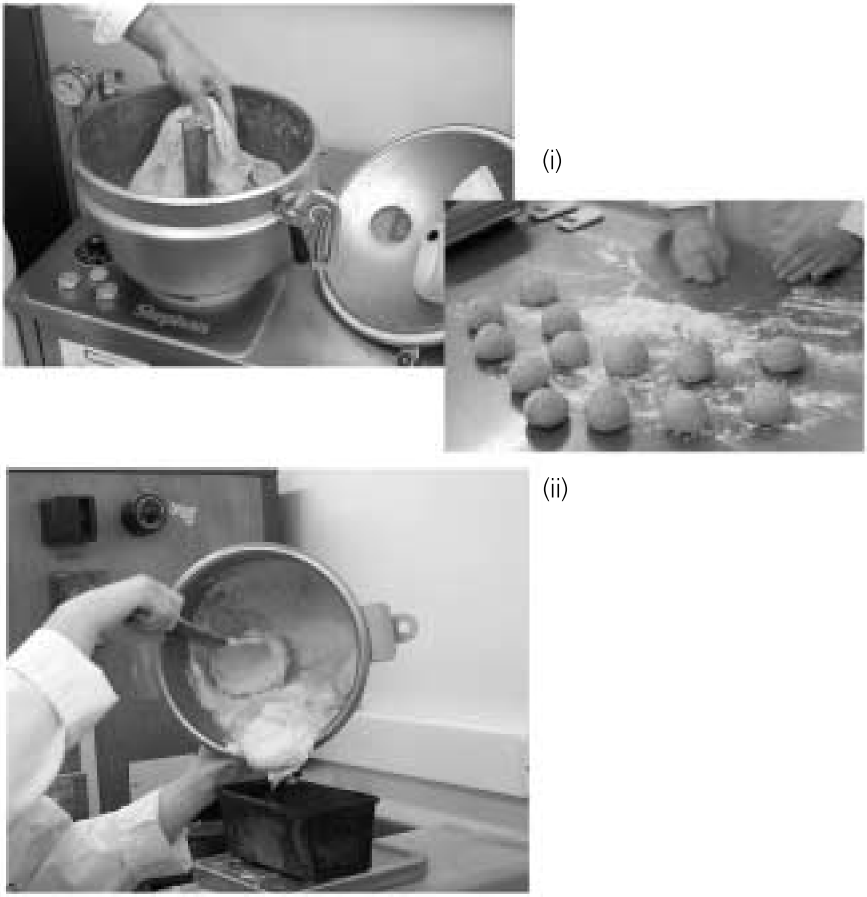


Figure 2: An elastic, extensible wheat dough (i), and a gluten-free batter (ii)

defects. Currently, many gluten-free products available on the market are of low quality, exhibiting poor mouthfeel and flavour.

Such problems are rarely encountered during the manufacture of gluten-free biscuits, as the development of a gluten network in biscuit and cookie dough is generally minimal and undesirable; the texture of baked biscuits is primarily attributable to starch gelatinization and supercooled sugar rather than a protein/starch structure.

This study used a fundamental and practical approach to develop high quality gluten-free bread and other cereal-based products. Novel and functional ingredients were added to gluten-free bread, biscuit and pizza base formulations, and their effects on overall appearance, crumb, shelf-life and sensorial characteristics, when compared with their gluten-containing counterparts, were measured. The bread products were developed at The National Food Centre and the biscuit and pizza base products at University College Cork.

THE IRISH MARKET FOR GLUTEN-FREE CEREAL PRODUCTS

A wide range of gluten-free cereal products ranging from breads to pizza and biscuits were collected and subjected to a range of tests including texture profile analysis, moisture determination, crumb density, crust and crumb colour. Sensory testing was carried out by assessing appearance (whole loaves, and slice appearance), crumbliness (in relation to spreadability of butter), mouthfeel, texture and flavour. Overall, it was found that most of the gluten-free products were of inferior quality and often had off-flavours. The structure of the products was mostly crumbly and very dry.

SECTION A: DEVELOPING GLUTEN-FREE BREAD FORMULATIONS USING NOVEL INGREDIENTS

METHODS USED TO ASSESS BREAD QUALITY:

- Loaf specific volume (cm^3) was measured using rapeseed displacement.
- Crust and crumb colour was measured with a Minolta Chroma Meter. This defines colour numerically in terms of lightness or L* value, (0=black, 100=white), a* value (greenness 0 to –100, redness 0 to +100) and b* value (blueness 0 to -100, yellowness 0 to +100). L*, b* and L*/b* readings are the most appropriate for bakery products.
- A texture analyser (TAXT2*i)* was used to assess crust and crumb characteristics (Figure 3). Crust penetration (cylindrical probe; 6mm diameter) and crumb texture profile analysis (cylindrical probe; 20mm diameter) were carried out to assess the staling profile of baked products.

Figure 3: The texture analyser (TAXT2i) is used to assess characteristics such as the hardness, springiness and staling rate of bread crust and crumb.

- Loaf moisture was measured by the AACC two-stage drying method (Standard methods no 62-05 and 44-15A).
- Digital image analysis was performed on the crumb grain by capturing images of the sliced breads using a flatbed scanner. The images were scanned full scale at 300 dots per inch and analysed in grey scale. A 60- x 60-mm square field of view (FOV) was evaluated for each image. This FOV captured the majority of the crumb area of each slice. Twelve digital images were processed and analyzed for each batch, giving a total of 60 images. Image analysis was performed using the SigmaScan Pro software.
- Protein content of the breads was measured by the Leco method (AOAC 968.06).
- Dietary fibre content was measured by the AOAC procedure (Fibertec System E).

TRIAL 1: Dairy ingredients in gluten-free bread formulations

A commercial wheat starch (Codex Alimentarius) gluten-free flour was supplemented with seven dairy powders (0, 3, 6, 9% inclusion rates based on flour weight). Dairy proteins are highly functional ingredients and due to their versatility can be readily incorporated into many food products. They may be used in bread for both nutritional and functional benefits including flavour and texture enhancement, and storage improvement. They may be used in a gluten-free bread formula to increase water absorption and therefore enhance the handling properties of the batter.

Materials/Methods:

The formulation per 100g gluten-free flour was: 87g water @35°C, 2.7g fresh yeast, 1g oil and 0.5g DATEM (a bread improver). Seven dairy powders (6.5 – 90% protein, Table 1) were added at 3, 6 and 9g. Breads were prepared by blending the liquid ingredients together. These were then added to the dry ingredients and mixed for a total of 3.5 min in a 3 speed Hobart mixer; 450g of batter was scaled into 1lb tins and placed in a proofer for 45 min (40°C, 80% RH). The batter was baked at 230°C for 25 min in a rotating oven. The loaves were cooled to room temperature and placed in polyethylene bags until tested.

Table 1: Type, abbreviation and protein content of the dairy powders used in the preparation of gluten-free breads.

Type (abbreviation)	Protein content (%)
Sweet whey powder (swp)	6.5
Demineralised whey powder (dwp)	11.0
Fresh milk solids (fms)	18.0
Spray dried milk solids (sms)	26.0
Spray dried skim milk (smp)	35.0
Sodium casein (nac)	89.0
Milk protein isolate (mpi)	90.0

Results:
Inclusion of dairy powders had a variable effect on loaf volume (Figure 4) and there were significant differences both between the powders and between the inclusion levels. Overall, inclusions of dairy powders reduced loaf volume by about 6%. Sodium caseinate and mpi have a high water-holding capacity. With increasing amounts of these powders, the resulting batters became visibly more viscous i.e. less like a batter and more like a dough. These breads had an appealing shape and were similar in appearance to wheat breads.

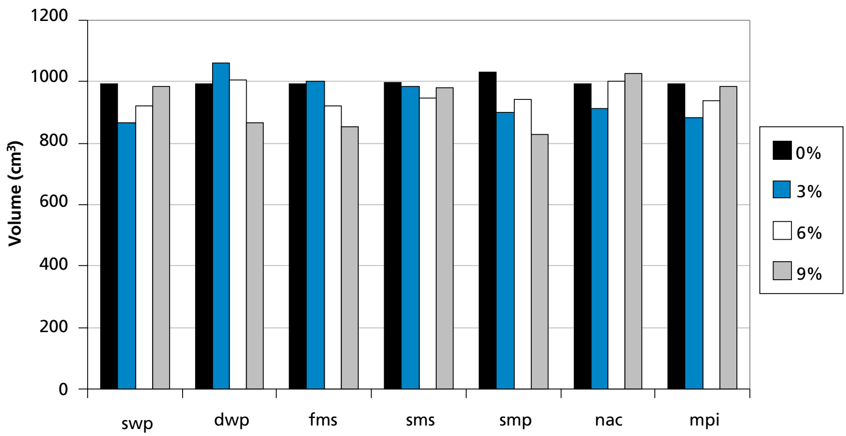


Figure 4: Influence of dairy powders and their level of inclusion on the loaf volume of gluten-free breads.

The lightness of the gluten-free bread crust varied widely with L* values ranging from 62 (3% smp inclusion) to 36 (9% nac inclusion). Breads containing the dairy powders were generally darker when compared to their gluten-free controls (zero dairy powder addition) (Figure 5). The darker colour (lower L* values) were expected and were due to Maillard browning and caramelisation which are influenced by the distribution of water and the reaction of reducing sugars and amino acids.

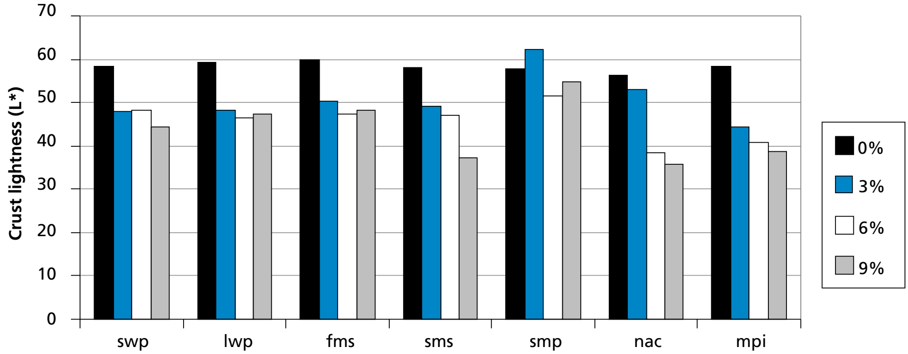


Figure 5: Influence of dairy powders and their level of inclusion on the crust lightness of gluten-free breads (low values indicate darker crust)

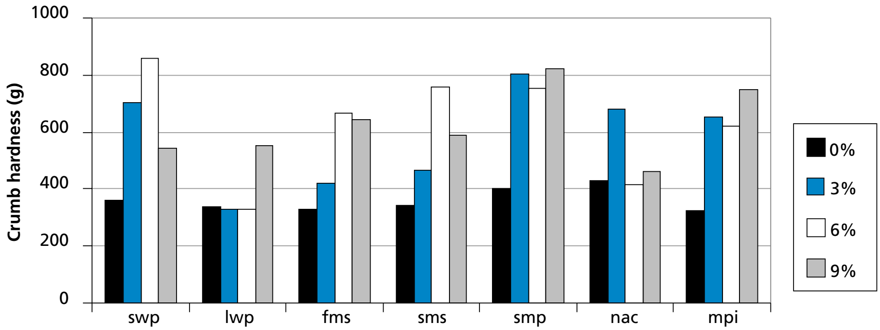


Figure 6: Influence of dairy powders and their level of inclusion on the crumb texture profile analysis (TPA) of gluten-free breads

Crumb colour (L*/b*) (white/yellow ratio) was influenced both by powder type and by level of addition. Protein types swp, fms, sms (with the exception of the lowest inclusion level) and smp resulted in crumb darkening compared with the control gluten-free bread, while nac resulted in a whiter crumb. The moisture contents of the gluten-free breads with the dairy powders were similar and all were in the range 39 to 42% w/w.

Breads with dairy powders of higher protein content tended to have the firmest (least soft) crumb compared to the control (without dairy powders, Figure 6). Swp was an exception in that it has a low protein and high lactose content but still gave a firm crumb. However, it was more similar in appearance and texture to ordinary wheat-containing bread than to the cake-like appearance of some gluten-free breads.

As there were eight products for testing, sensory analysis took place over two sittings. The first (20 tasters) evaluated the control gluten-free bread and four breads containing dairy powders (dwp, sms, smp, mpi). The second (20 tasters) session embraced the same control bread and three breads with the remaining dairy powders (swp, fms, nac). In the first session, three out of the four gluten-free breads were given a higher acceptability score than the gluten-free control. Bread containing smp was judged to be significantly more acceptable than the other samples. In the second session, similarly, all breads containing the dairy powders received higher acceptability scores than the control but the effect was not statistically significant.

The high protein powders increased the protein contents of the breads from about 2.4% (control) to about 5.0% (breads with nac and mpi) (Figure 7).

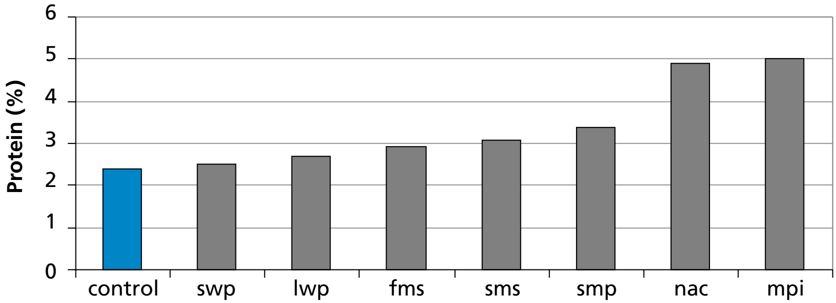


Figure 7: Protein content of gluten-free breads supplemented (6% inclusion level) with dairy powders (see Table 1 for powder composition).

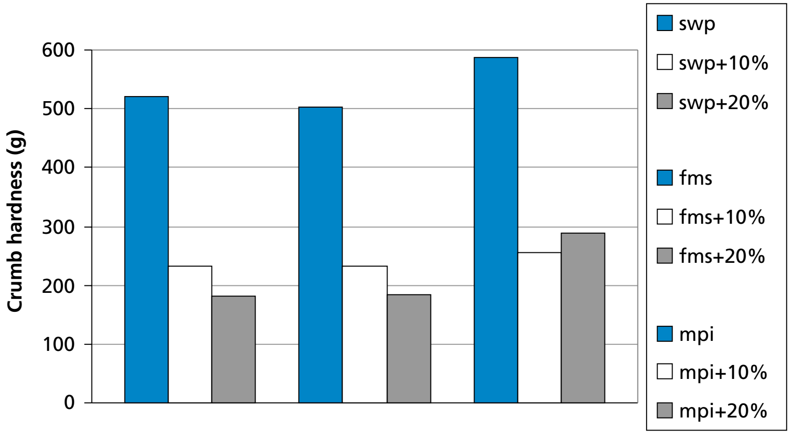


Figure 8: Influence of dairy powders plus additional water (10 or 20%) on the crumb hardness of gluten-free breads.

The moisture content of the breads was a major factor in regulating the loaf volume and crumb and crust texture. Therefore, the effect of increasing water addition in the batter by 10 and 20% was studied. Loaf volumes increased in the breads containing all three powder types, with volumes peaking at 10% extra water. Both crust and crumb hardness were reduced with increasing water addition (Figure 8). However, the level of water addition was excessive and resulted in loaves that were too soft for 'easy' slicing. Starch retrogradation is strongly influenced by the moisture content of the product and the softness of the crumb in this additional study may be attributed to a reduction in starch retrogradation due to the presence of extra water, resulting in a softer crumb overall. Photographs of some breads are shown in Figure 9.

Conclusions from Trial 1:

- Dairy powders added to a gluten-free bread formulation improved both the textural characteristics and the nutritional content of the breads without changing the processing conditions.
- Powders with a high protein (smp, nac, mpi) content generally gave breads with a lower loaf volume and an increased crumb and crust hardness. These breads had an appealing dark crust and white crumb appearance, and received good acceptability scores in sensory tests.

- Additional water in the gluten-free formulation resulted in increased loaf volume and a much softer crust and crumb texture than the controls.
- Supplementing the gluten-free formulation with high protein dairy powders doubled the protein content of the breads.

TRIAL 2: The effect of dairy and rice powder addition on loaf and crumb characteristics, and on shelf of gluten-free breads stored in a modified atmosphere.

The shelf-life of bread is mainly influenced by loss of moisture, staling and microbial deterioration. Of these, staling is the main limiting factor. The bread-making process, including dough recipe, method of mixing and proofing, temperature of the dough during baking and the final packaging, affect staling of bread loaves. The staling mechanism is complex; crumb firmness increases, the crust becomes softer, and the bread loses its fragrance, assuming a stale flavour. The retrogradation of starch is significant in the staling process, whereby changes in the amylopectin within the starch granule occur over time. However, it is well documented that bread firming is not synonymous with starch recrystallisation; it may be due to starch-gluten interactions, where

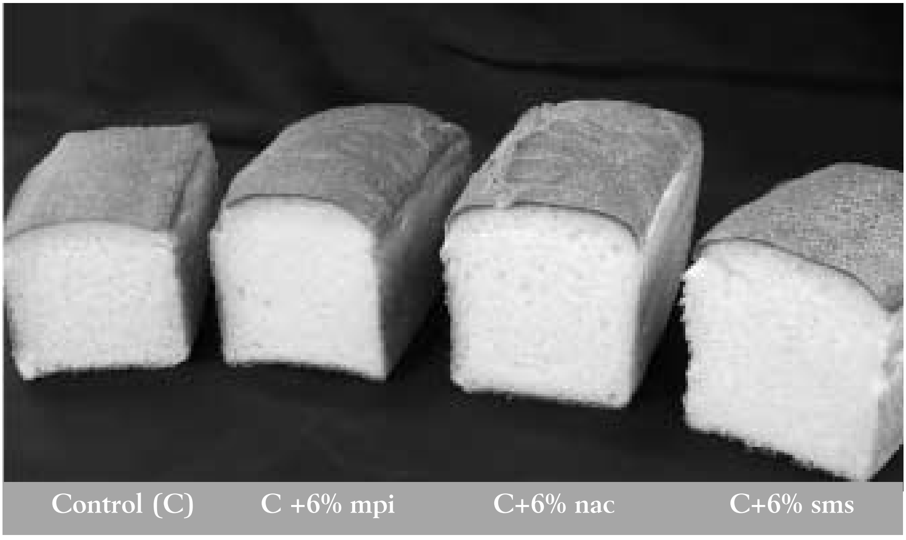


Figure 9: Gluten-free breads without (C) and with 6% added dairy powders (Trial 1).

gluten is crosslinked by gelatinised starch. Changes in the firming rate of bread may also be due to hydrogen bonding between gluten and starch granules.

Little published work is available on the staling profile of gluten-free breads, stored either in air or in a modified atmosphere. Gluten present in wheat bread slows down the movement of water by forming an extensible protein network, thus keeping the crumb structure together. Therefore, the absence of gluten should increase the movement of water from the bread crumb to crust, resulting in a firmer crumb and a softer crust. Trial 2 studied *(i)* the effects of addition of 3% milk protein isolate and 3% rice starch to a wheat-starch-based gluten-free bread formulation, and *(ii)* examined the intermediate (8 days) and long term (43 days) staling profile of both gluten-free bread formulations, packed in an 80% carbon dioxide/20% nitrogen atmosphere.

Materials/Methods:

The control gluten-free formulation contained commercial wheat starch; this was supplemented with a dairy powder (3%) (milk protein isolate) obtained from Kerry Ingredients (Listowel, Co. Kerry, Ireland), and 3% of a novel rice starch obtained from Leckpatrick Dairies, Strabane, Co. Tyrone, N. Ireland. Thereafter, the gluten-free formulation, the production of the gluten-free loaves and subsequent analysis of the loaves was identical to that described in Trial 1. The baked loaves were packed in an atmosphere of 80% carbon dioxide /20% nitrogen using an A300 CVP packaging machine (CVP Systems Ltd., England) and left at room temperature until tested. The test breads are referred to as CRD breads [i.e. control formula (C) supplemented with rice starch (R) and dairy powder (D)] for convenience. For intermediate term analysis, testing took place on days 0 (day of baking), 2, 4 and 8. For long term analysis, testing took place on days 0, 9, 23 and 43.

Results:

[A] Effects of rice starch and dairy powder addition on the baking characteristics of gluten-free breads:

Addition of rice starch and dairy powder increased loaf volume. Also, gluten-free breads with these additional ingredients (CRD) had a better external appearance and resembled wheat-bread loaves more closely than the gluten-free control.

The CRD loaves were darker in colour (lower crust L*) than the control (Figure 10). This is to be expected as the dairy powder contained a small amount of lactose which contributes to Maillard browning and caramelisation reactions. Crumb colour (L*, L*/b*) was not significantly influenced by either dairy powder or rice starch addition.

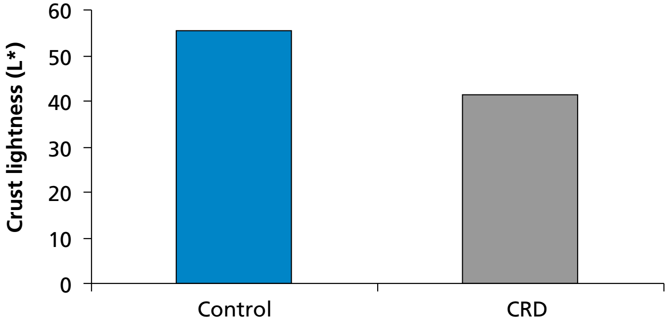


Figure 10: Influence of rice starch and dairy powder addition (CRD) on the crust colour (L*) of gluten-free breads.

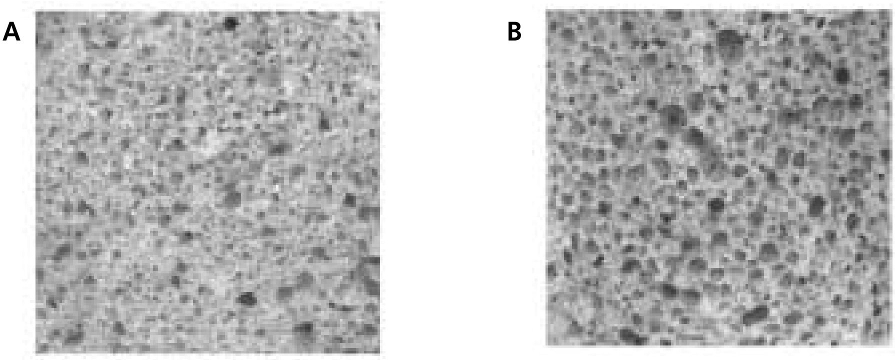


Figure 11: Sample images of 60 x 60 mm field of view of gluten-free breads; control gluten-free bread (A) and control with rice starch and dairy powder added (CRD), (B).

Images from each bread type (control; CRD) are shown in Figure 11. Digital image analysis revealed that the total number of gas cells decreased with addition of the powders to the gluten-free formula (1583-control v 1229-CRD). Thus the number of cells/cm^2 was 44.0 (control) and 34.1 (CRD). The results for the CRD loaf were similar to those found in studies with wheat bread loaves, in that the number of small cells in the range 0.05 to 4mm^2 decreased by about 25% after addition of the dairy and rice powders (1358 vs 1006). The CRD loaves had a more open structure, compared to the typical cake-like tight structure/appearance of some gluten-free breads.

[B] Effects of modified atmosphere packaging (MAP) (80% carbon dioxide, 20% nitrogen) on the intermediate and long-term shelf-life of gluten-free breads with rice starch and dairy powder:

Crust and crumb texture:

Movement of water from crumb to crust was evident over the testing (i.e. the crust became softer and the crumb texture hardened). The CRD loaves had a softer crust on day 0 than the control and thereafter throughout the 8-day staling trial (Figure 12). However, the rate of decrease of crust hardness was largely unaffected by the addition of the rice starch and dairy powder i.e. these loaves remained softer than the control but staled at a similar rate. An overall significant decrease in crust hardness was found for the intermediate and long-term trials for these breads. Within the modified atmosphere package, it appeared that crust hardness reached a minimum after two days and further testing beyond this revealed no significant changes to the crusts of either the control or the CRD loaves.

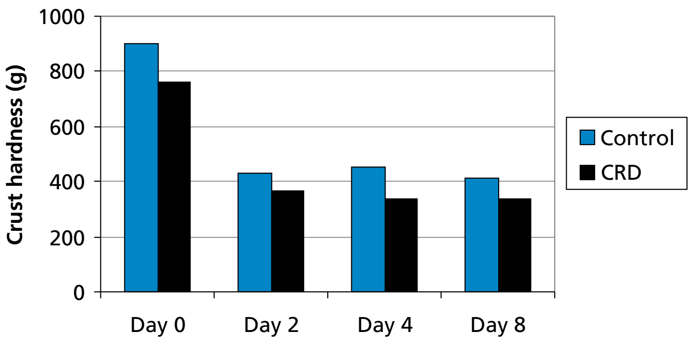


Figure 12: Influence of rice starch and dairy powder addition (CRD) plus modified atmosphere packaging on the crust hardness of gluten-free breads stored over an 8 day period.

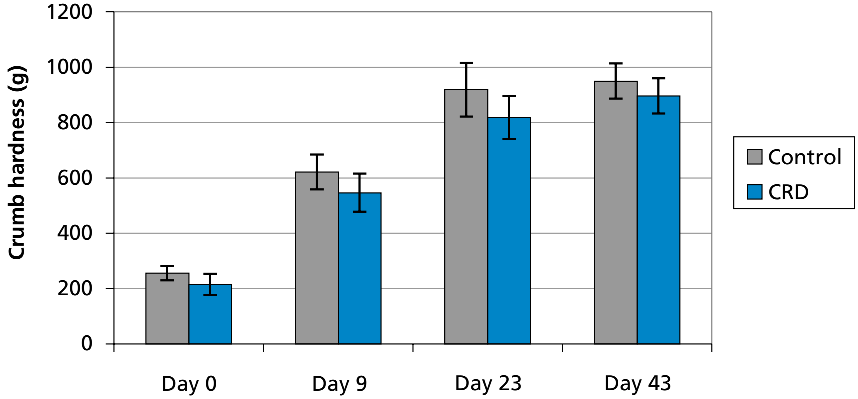


Figure 13: Influence of rice starch and dairy powder addition (CRD) plus modified atmosphere packaging on the crumb hardness of gluten-free breads stored over a 43 day period.

The most notable changes in crumb characteristics, i.e. hardness and springiness, occurred during the first 23 days of the storage period for both gluten-free bread formulations in the intermediate and long-term staling studies. The hardness values were lower for the CRD loaves but no significant difference was found for the rate of staling between the two formulations. Between days 0 and 9, crumb hardness increased linearly with time, reaching a maximum value after 23 days and no further increase occurred between testing days 23 and 43 (Figure 13).

A negative correlation was found between loaf volume and crumb hardness: smaller loaves (as in the case of the control) were denser and had a tightly packed crumb structure, resulting in higher crumb hardness readings.

In a paired visual comparison, the overall preference was for the CRD loaves. Panellists commented that this bread "looked more like real bread", that the crumb was "more even and more airy than the control", and that the loaves had "better volume and crust colour, like wheat bread". Of the 30 assessors in the tasting trial, 16 showed a preference for the CRD and 14 for the control i.e. no significant difference was found.

Conclusions from Trial 2:

- Milk protein isolate and rice starch added to a wheat-starch-based gluten-free bread formulation boosted loaf volume, increased crumb softness and improved the overall appearance of the loaves.

- Although the loaves did have softer crust and better crumb characteristics, loaves from both formulations staled at a similar rate.
- The most notable changes to crust hardness occurred within the first 9 days.
- Peak crumb hardness values were attained between days 23 and 43; however, there was no significant increase in hardness after day 23.

TRIAL 3: Fish surimi and inulin in breads made without wheat flour

Fish surimi is a colourless, odourless, refined form of fish meat. It is high in protein and has unique gel-forming properties due to the presence of water insoluble myofibrillar proteins. Inulin is a non-digestible polysaccharide, which has a positive health effect on the host by stimulating the growth or activity of beneficial bacteria in the colon. It may be incorporated into baked goods for both its nutritional (prebiotic/dietary fibre) and its technological (texture/rheology modifier) properties.

(i) A control wheatstarch-free gluten-free bread formulation based on rice and potato starch was supplemented with fish surimi (as a potential structure enhancer) at an inclusion level of 10% of starch weight. Frozen surimis from mackerel, blue whiting, red gurnard and pollock were evaluated.

(ii) In a second study, the same control formulation was supplemented with inulin.

Materials/methods

Fish surimis: Frozen samples (supplied by IFREMER, France) of mackerel *(Scomber scombrus)*, gurnard *(Aspitrigla cuculus)*, blue whiting *(Micromesistius poutassou)* and pollock *(Pollachius pollachius)* surimi were added to a gluten-free bread formulation at 10% of flour weight. The frozen surimi samples had a moisture content of circa 80% (based on freeze-drying tests).

Inulin: A sample of Raftiline (inulin) was obtained from Orafti Food Ingredients, Belgium.

Bread formulation and baking:

(i) A control (CB) gluten-free dough was prepared using a formulation based on rice flour (50g), potato starch (50g), skim milk powder (10g), vegetable oil (6g), sugar (5g), fresh yeast (5g), salt (2g), xanthan gum (0.3g), hydroxypropylmethylcellulose (HPMC; 0.3g), and water (85g). A second control (CWB) was prepared with an equal water content to the surimi doughs (to take account of the amount of water supplied to the formulation by the surimi). The latter were prepared using frozen surimis which were tempered overnight at 4°C, mixed with water and yeast to form a slurry, and added to the premixed dry ingredients. The baking procedure was carried out as described in Trial 1.

(ii) The same control (C) gluten-free formulation as described in (i) was used. This was then supplemented with 4% and 8% inulin (based on flour/starch weight).

Results and Discussion

(i) Formulation supplemented with fish surimi.

The control gluten-free bread (CB) had the lightest crust colour of the six samples, while the control bread with added water (CWB) had the lightest crumb colour (Table 2). The addition of extra water and/or fish surimi darkened crust colour. However, surimi type *per se* did not influence crust or crumb colour. This was unexpected as the freeze-dried blue whiting and mackerel surimis were darker than the pollock and gurnard surimis (Minolta L^*/b^*: 2.95, 2.96, 4.18 and 4.59 respectively). However, the amount of surimi (on a dry matter basis) added was circa 2% of flour (rice flour + potato starch) weight and may have been insufficient to dull the white appearance of the starches in the bread crumb.

With the exception of the gurnard surimi breads (GSB), the addition of surimi gave a softer crust and crumb than the control breads (CB and CWB). The firming effect of gurnard surimi may be due to its high water-binding properties which result in more hydrogen bonding between the bread starches and fish and dairy proteins, and also a higher level of starch retrogradation. Water-holding capacities of freeze-dried surimis were 481 (gurnard), 382 (pollock), 326 (mackerel) and 306% (blue whiting). Staling patterns were the

Table 2: Effect of fish surimi on the colour and texture of gluten-free breads

	Colour[1]		Texture[2]	
Bread	Crust lightness (L*)	Crumb lightness (L*)	Crust hardness (g)	Crumb hardness (g)
Control bread (CB)[3]	58	82	316	452
Control + water (CWB)	52	86	229	331
Mackerel (MSB)	53	82	217	177
Gurnard (GSB)	53	82	376	534
Blue whiting (BSB)	51	83	180	127
Pollock (PSB)	52	82	223	154

[1]Minolta lightness values (L*); tested after 24h
[2]Measurements taken 24h post-baking
[3]Abbreviated terms for the breads

same for the four surimi breads in that crust hardness decreased and crumb hardness increased over days 1, 2 and 3 post-baking.

BSB and MSB had the highest loaf volumes while GSB had the lowest volume. The PSB, GSB and CB breads had the smallest gas cells and there was a negative relationship between loaf volume and number of gas cells per cm^2. There was also a negative correlation between loaf volume and crumb firmness.

Paired comparison taste panel tests for acceptability between the control and surimi breads indicated that BSB bread was preferred to the control (15/5 preference ratio). Preference ratios for the other comparisons were 11/9 (MSB vs CB), 10/10 (PSB vs CB) and 8/12 (GSB vs CB). The panellists preferred the breads with the soft crust/crumb texture. Photographs of the different breads are shown in Figure 14.

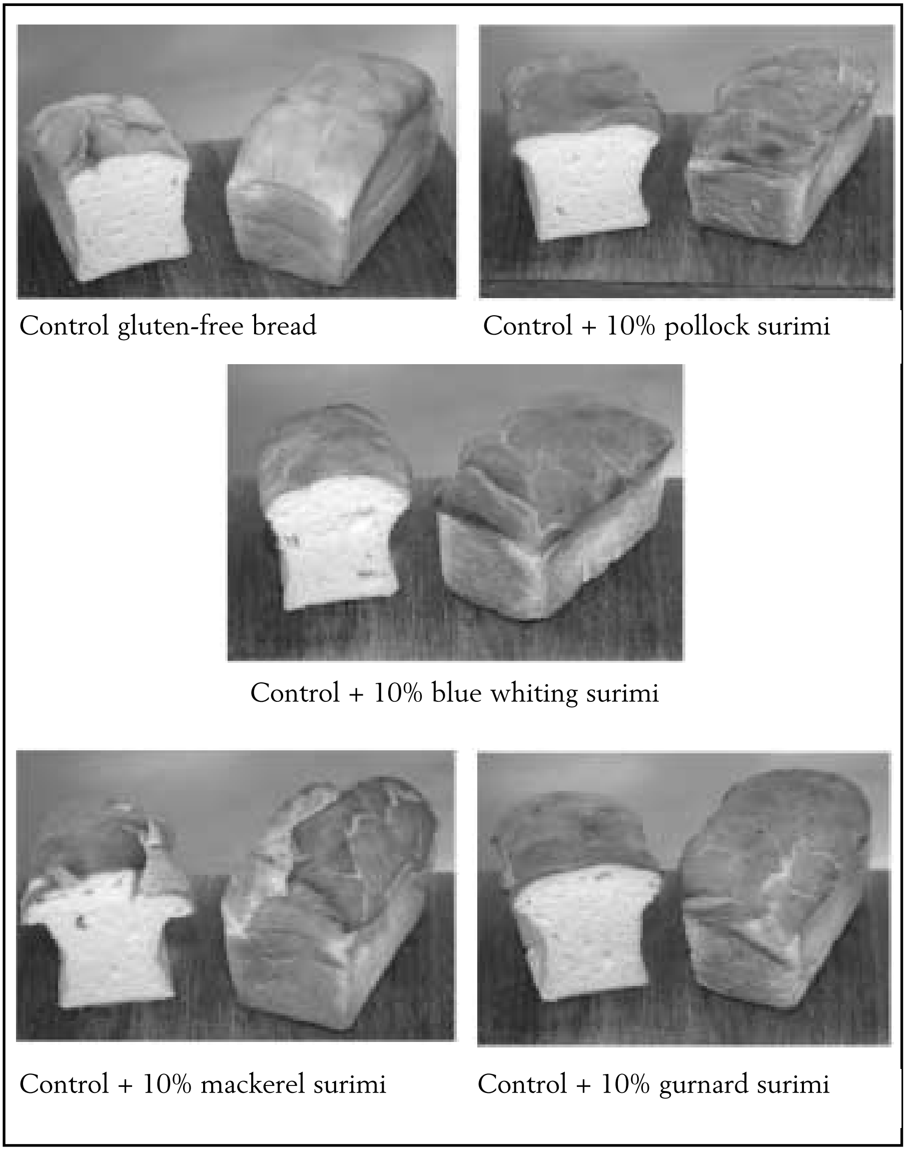


Figure 14: The control gluten-free bread and gluten-free breads containing 10% (w/w) fish surimi from pollock, blue whiting, mackerel and gurnard.

(ii) Formulation supplemented with inulin.

The inclusion of inulin at 4% and 8% of starch weight considerably altered the characteristics of the gluten-free breads. At the 4% level, loaf volume was significantly increased. At both levels of inclusion, loaf appearance was darker probably due to the enzymes in the yeast hydrolyzing part of the inulin, resulting in the formation of fructose and thus causing a browning of the loaf crust. Crust hardness was also reduced with increasing levels of inulin. At the 8% level of inclusion, dietary fibre content of the loaves was 7.5% (Figure 15); this is in contrast to the gluten-free control loaf (1.4%) and an ordinary wheat bread loaf (3.7%). Photographs of the breads containing inulin are seen in Figure 16.

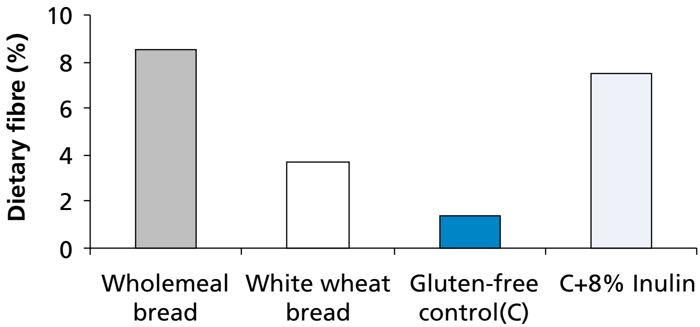


Figure 15: Dietary fibre contents of wholemeal and white wheat breads compared with gluten-free bread and gluten-free bread with added inulin.

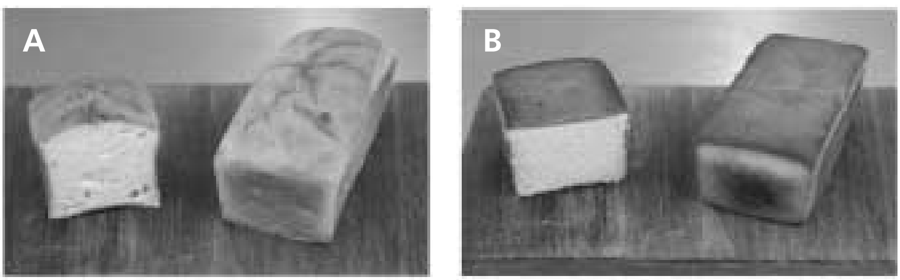


Figure 16: Gluten-free formulation with 4% (A) and 8% (B) inulin inclusion.

Conclusions from Trial 3:

- Surimi and inulin may be used in wheatstarch-free gluten-free bread formulations as texture improvers (surimi) or as nutritional enhancing ingredients (inulin).
- Three of the surimis (gurnard surimi excepted) have potential as crust/crumb softeners in gluten-free breads.
- Breads with blue whiting surimi were preferred to the control in sensory tests. Inulin enhanced the nutritional value of the breads by increasing the dietary fibre content.

TRIAL 4: Optimising the formulation of breads made without wheat flour

Response surface methodology was used to optimise a gluten-free bread formulation based on rice flour, potato starch and skim milk powder. Hydroxypropylmethylcellulose (HPMC) and water were the predictor variables. Gums and hydrocolloids such as HPMC can improve gas retaining and water absorbing characteristics usually supplied by wheat gluten. HPMC has affinity for both the aqueous and non-aqueous phases of a dough system, therefore maintaining uniformity and stability. However, during baking the HPMC polymers lose their affinity for water and gel with one another instead. This causes an increase in viscosity, strengthens gas cell walls and prevents excess moisture loss. The gel network does not linger after cooling and there are no adverse effects on the texture of the final product. Rice bread of comparable quality to wheat bread was obtained by incorporating HPMC (Ylimaki *et al.*, 1988; Cato *et al.*, 2001). HPMC has also been used as an improver in wheat bread, yielding better specific volume, softer crumb and enhanced sensory characteristics (Collar *et al.*, 1999; Rosell *et al.*, 2001).

Response surface methodology (RSM) is a statistical technique that allows optimum ingredient levels to be determined while at the same time minimizing the number of baking trials without losing any information related to all possible experimental combinations. RSM can quantify the main effects of the ingredients and describe the interactions between them. This study developed an optimised gluten-free bread formulation using RSM, thereby determining the critical levels of HPMC and water.

Materials/Methods:

The formulation (per 100g of flour/starch weight) was 50g rice flour, 50g potato starch, 10g skim milk powder, 6g vegetable oil, 5g fresh yeast, 5g sugar and 2g salt. A central composite design consisting of two variables, HPMC and water was prepared. Analyses of breads from the 13 experimental treatments were performed 24 hours after baking. Assessment of error was derived from 5 replications of one treatment combination. From the data obtained, optimal ingredient levels were determined and eight baking trials were performed for both the evaluation of the optimised formulation and for the short-term shelf-life study on the optimised formulation. (In the study on the optimised formulation, two loaves from each replicate were packaged in a 60% N_2/40% CO_2 atmosphere and were tested on days 1, 4 and 7).

Results:

Specific volume and loaf height increased as water levels increased (Figure 17). (Hydrocolloid addition usually increases water retention and loaf

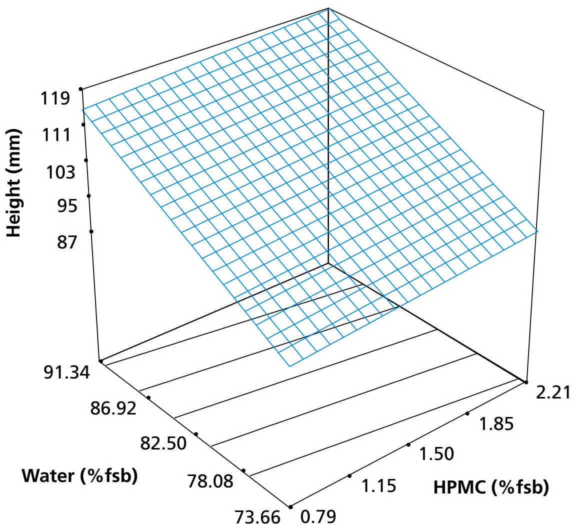


Figure 17: Effect of HPMC and water addition (% flour: starch basis) on loaf height. Gluten-free breads were made without wheat flour and with rice flour, potato starch and skim milk powder.

volume). However, a slight decrease in specific volume was found with increasing HPMC. It is noteworthy that the treatments yielding the highest specific volume and loaf heights gave poor quality breads with very large gas cells, thereby not truly reflecting specific volume.

Crumb lightness (L*) values increased (i.e. crumb became whiter) as levels of both water and HPMC increased. This was correlated with a higher loaf specific volume and a more open crumb grain that resulted when higher levels of these ingredients were used.

One of the most undesirable characteristics of gluten-free rice breads is a firm and crumbly texture due to the starch base. While the crumb became softer as water levels increased (Figure 18), higher levels of HPMC increased crumb firmness. The softening effect of high water levels can be attributed to the higher specific volume and less dense crumb structure found in these breads. Crumb grain analysis showed significant interactions between water and

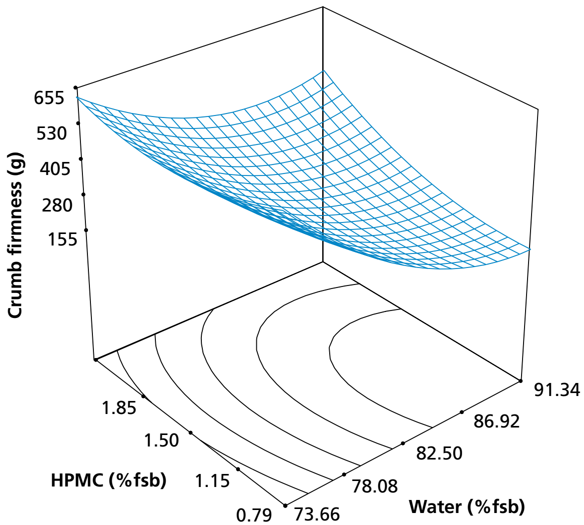


Figure 18: Effect of HPMC and water addition (% flour: starch basis) on crumb firmness of gluten-free breads made without wheat flour and with rice flour, potato starch and skim milk powder.

HPMC for the number of cells/cm^2 (Figure 19). The reduction in the number of cells/cm^2 in the treatments with the highest water addition and resultant higher specific volume may be due to the presence of large gas cells in these breads. The recipe with the lowest specific volumes gave the highest number of cells/cm^2. This is in agreement with Cato *et al.* (2001), who reported a more uniform cell size and structure in gluten-free breads with a smaller specific volume.

The characteristics of good quality bread are an optimum specific volume and crumb grain, and low crumb firmness. Optimisation was based on the generation of the best characteristics. The optimised levels obtained were 2.21% HPMC and 79.05% water. Specific volume and loaf height compared favourably to the predicted values that were generated by the software (Table 3). Crumb firmness values were lower than those predicted. Crumb grain analysis revealed a lower number of small cells and a higher number of large cells than predicted.

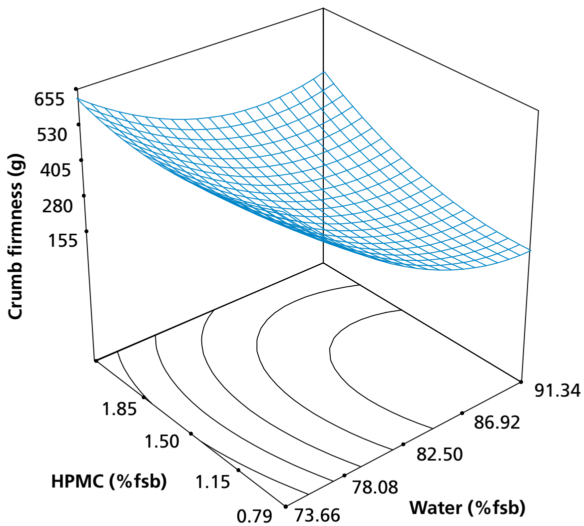


Figure 19: Effect of HPMC and water addition (% flour: starch basis) on the number of cells/cm^2 in gluten-free bread made without wheat flour and with rice flour, potato starch and skim milk powder

Table 3: Comparison of predicted and measured values for bread quality using an optimised gluten-free formulation

Bread quality	Predicted value	Measured value
Specific volume (mlg-1)	3.08	3.03 ± 0.16
Loaf height (mm)	99	104 ± 10
Crumb firmness (g)	461	313 ± 49
Number of small cells (a)	851	773 ± 37
Number of large cells (b)	21	24 ± 2
a 0.05 – 4.00 mm^2, b > 4.00 mm^2		

Table 4: Analysis of crust and crumb characteristics and crumb moisture for the optimised formulation over a 7-day testing period

Parameter	Day-1	Day-4	Day-7
Crumb firmness (g)	365 ± 65	514 ± 89	565 ± 105
Crust firmness (g)	539 ± 111	472 ± 118	425 ± 75
Crumb springiness	0.81 ± 0.03	0.77 ± 0.03	0.75 ± 0.04
Crumb resilience	0.36 ± 0.03	0.30 ± 0.04	0.27 ± 0.03
Crumb moisture (%)	47.50 ± 0.22	46.60 ± 0.33	45.99 ± 0.56

Shelf-life of the gluten-free breads from the optimised formulation:

The optimised formulation was baked and tested over a 7-day period. Texture profile analysis showed that crumb springiness decreased over time (Table 4), which is indicative of an increase in brittleness. As gluten-free breads typically have higher moisture than wheat breads, starch retrogradation may progress more rapidly during storage of gluten-free breads. Crumb moisture decreased over the 7-day trial, signifying the migration of moisture from crumb to crust. These findings support the hypothesis that the rate of staling is a function of bread moisture, with moisture content being inversely proportional to the rate of staling (Rogers *et al.*, 1988). The gluten network in wheat bread slows the movement of water and therefore, the absence of gluten in bread can result in accelerated moisture migration from crumb to crust. A photograph of the optimised bread is given in Figure 20.

Conclusions from Trial 4

- Response surface methodology was used to optimise HPMC and water levels in a wheatstarch-free gluten-free bread; the optimised levels were 2.2% HPMC and 79% water which yielded good quality bread.
- Water had a greater effect on the quality of gluten-free bread than HPMC. Increasing water significantly increased loaf specific volume and height, and decreased crumb firmness.
- Crumb colour became lighter as HPMC content increased.
- Both HPMC and water had significant effects on crumb grain structure (the number of cells/cm^2 increased as HPMC and water increased).

Figure 20: The optimised gluten-free bread formulation.

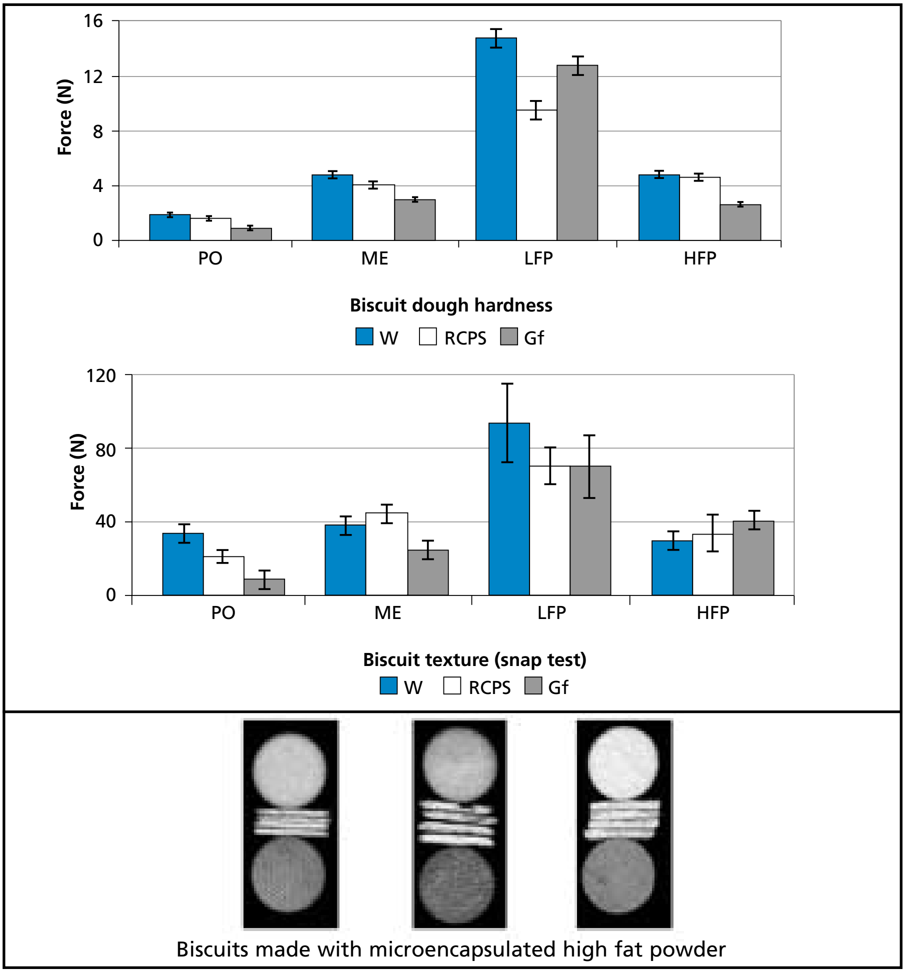
SECTION B: DEVELOPMENT OF GLUTEN-FREE BISCUITS AND PIZZA BASES

The research partners in University College Cork studied gluten-free biscuits and pizza bases. More information on the procedures and results is available in publications listed at the end of this report.

Gluten-free biscuits. Their diverse combinations of texture and taste have given biscuits and cookies universal appeal. The three principal ingredients in these products are wheat flour, fat and sugar. In different combinations, they form the basis of a full range of biscuit products. In gluten-free biscuits the wheat flour, which originates from soft winter wheat, is replaced by other ingredients. These not only replace the starch, which is normally delivered by the wheat flour, but also the protein fractions. An advantage in developing gluten-free biscuits (in comparison with gluten-free breads) is that gluten network formation is unwanted in many biscuit products. This study developed a short dough biscuit which is similar to wheat-based products. Starches sourced from corn, soya, millet, buckwheat, rice and potatoes were combined with different types of fat (palm oil, cream powder, microencapsulated high fat powder and low fat dairy powder). The dough characteristics as well as the biscuits' texture, colour and moisture, dimensions and sensory attributes were evaluated. Combinations of rice, corn, potato and soya with high fat powders produced biscuit doughs (which were sheetable) and biscuits of comparable quality to the control wheat biscuits (Figure 21).

Gluten-free pizza bases. The quality of gluten-free pizza products is generally poor and closer to a cake product than to a wheat dough pizza. The criteria for a good quality pizza are a sheetable dough, which rises on proving and holds the gas produced by the yeast, and also good textural and sensory attributes. A combination of gluten-free flours and starches, protein sources (egg, soya), hydrocolloids (guar gum), and a microencapsulated high fat powder delivered all these requirements.

Tests on dough hardness, pizza base hardness, colour and pizza volume confirmed that it is possible to produce gluten-free pizza products with similar attributes to wheat flour pizzas (Figure 22).



PO=palm oil

ME=microencapsulated fat powder

LFP=low fat powder

HFP=high fat powder

W=wheat-based

RCPS=rice, corn, potato and soya-based

Gf=commercially available gluten-free flour

Figure 21: Gluten-free biscuits compared with wheat biscuits for dough hardness, biscuit snap values and shape.

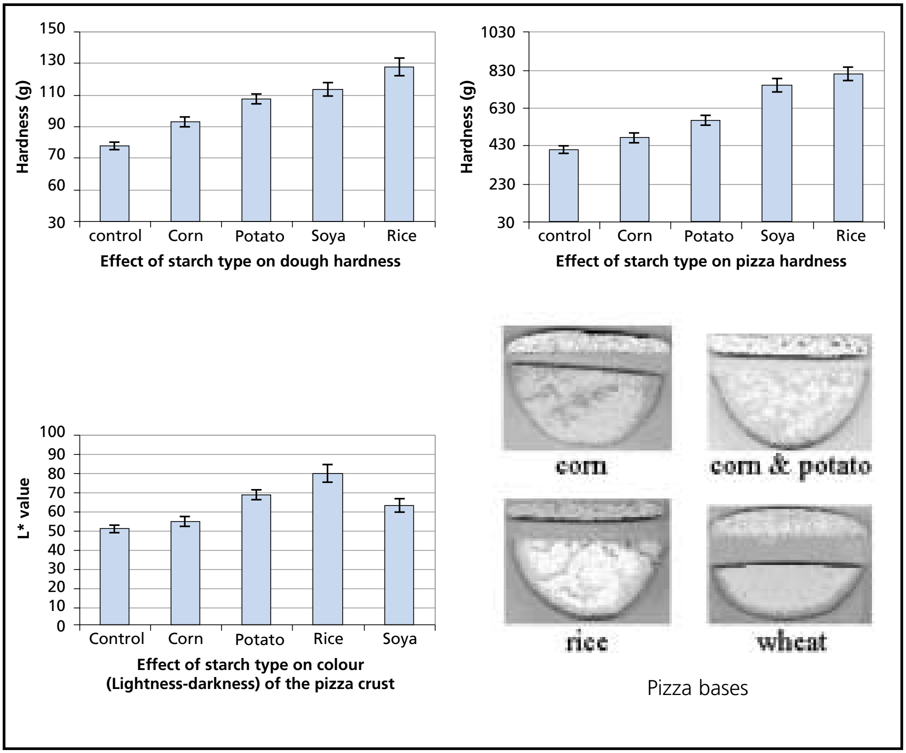


Figure 22: Quality of pizza bases produced with different gluten-free flours and the wheat flour control. Best option: corn starch in combination with guar gum and microencapsulated high fat powder.

The influence of the various ingredients on the dough rheology of the optimised recipe was tested using oscillation tests in the linear viscoelastic region (performed at 16 frequencies ranging from 0.01 to 10 Hz). From measurements of phase angle, complex modulus and elastic modulus it was clear that the biggest increase in elastic modulus was achieved when guar gum was combined with high fat powder in a cornstarch system.

CONCLUSIONS

- Dairy powder improved the texture and nutritional value of gluten-free breads.
- Milk protein isolate and rice starch boosted loaf volume, reduced crumb hardness and improved the overall appearance of wheatstarch-based gluten-free bread.
- Surimi modified the texture and inulin enhanced the nutritional value of breads formulated without wheat flour.
- The optimised HPMC and water levels in a non-wheat flour bread were 2.2% and 79% respectively.
- Combinations of rice, corn, potato and soya with high fat powders produced biscuit doughs that were sheetable and of comparable quality to wheat flour biscuits.
- Combinations of gluten-free flours, starches, protein sources (egg, soya), hydrocolloids (guar gum) and a microencapsulated high fat powder gave gluten-free pizza products with similar attributes to a wheat-based counterpart.

RECOMMENDATIONS TO INDUSTRY

Combinations of xanthan gum and/or hydroxypropylmethylcellulose together with a rice flour/potato starch base produce gluten-free bread of high quality. In addition, dairy powders, inulin and fish surimi enhance this gluten-free bread formulation and boost the dietary fibre and/or the protein content of the bread.

The optimised gluten-free bread formulation developed at The National Food Centre results in a smooth, pumpable, batter-type system and a good quality white yeast bread when baked. Proofing and baking is similar to that of wheat bread and extra ingredients (surimi and inulin) may be included with the dry mix.

RELATED CEREAL AND BAKERY RESEARCH ACTIVITIES AT THE NATIONAL FOOD CENTRE

Research: Ongoing/recently completed projects include: (a) formulation of reduced fat cakes and biscuits; (b) producing breads and confectionery products from organic ingredients; (c) tailoring flours for pizza production; (d) enzymatic modification of baked goods.

Milling and test-baking: Milling and baking quality of wheat cultivars are combined with data from field trials and recommendations are made by the Department of Agriculture and Food on the best cultivars.

Services for industry: These embrace flour testing, formulation, product development, dough and batter rheology, test baking, packaging, freezing, gas flushing and sensory analysis of baked goods. Identification of foreign bodies in bakery products is a priority as is the evaluation of yeast strains for different baking applications. Grain/flour quality tests are conducted, including hardness index, Falling Number, gluten status, moisture and protein contents.

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SELECTED PUBLICATIONS FROM THIS PROJECT

Gallagher, E., Gormley, T.R. and Arendt, E.K. 2003. Crust and crumb characteristics of gluten free breads. *Journal of Food Engineering*, **56**: 153-163.

Gallagher, E., Kunkel, A., Gormley, T.R. and Arendt, E.K. 2003. The effect of dairy and rice powder addition on loaf and crumb characteristics, and on shelf life (intermediate and long-term) of gluten-free breads stored in a modified atmosphere. *European Journal of Food Research* **218:**44-48.

Gallagher, E., Gormley, T.R. and Arendt, E.K. 2004. Recent advances on the formulation of gluten-free cereal-based products. *Trends in Food Science and Technology* **15**:18-23

McCarthy, D., Gallagher, E., Schober, T., Gormley, T.R. and Arendt, E.K. 2004. Application of response surface methodology in the development of gluten-free bread. *Submitted to Cereal Chemistry.*

Gallagher, E., Gormley, T.R., Elbel, C. and Arendt, E.K. 2004. Fish surimi as a gluten-free bread improver *(in preparation)*.

Gallagher, E., Gormley, T.R., Schober, T. and Arendt, E.K. 2004. Fundamental rheology and confocal microscopy studies of gluten-free batters containing different protein sources *(in preparation)*.

Schober T., O'Brien, C. and Arendt, E.K. 2003. Effects of microencapsulated high fat powders on the quality of gluten-free biscuits. *European Journal of Food Research and Technology*, **216**:369-376.

REFERENCES

Bloksma, A.H. and Bushuk, W. 1998. Rheology and chemistry of dough. In Pomeranz, *Wheat: Chemistry and Technology*, 131-200. AACC Inc., St. Paul, Minnesota, USA.

Cato, L., Rafael, L.G.B., Gan, J. and Small, D.M. 2002. The use of rice flour and hydrocolloid gums for gluten-free breads. *Proceedings of the 51st Australian Cereal Chemistry Conference*, 304-308.

Collar, C., Andreu, P., Martinez, J.C. and Armero, E. 1999. Optimisation of hydrocolloid addition to improve wheat bread dough functionality: a response surface methodology study. *Food Hydrocolloids*, **13**:467-475.

Feighery, C.F. 1999. Coeliac disease. *British Medical Journal*, **319:** 236-239.

Rosell, C.M., Rojas, J.A. and de Barber, B.C. 2001. Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids*, **15**:75-81.

Ylimaki, G., Hawrysh, Z.J., Hardin, R.T. & Thomson, A.B.R. 1991. Response surface methodology in the development of rice flour yeast breads: sensory measurements. *Journal of Food Science*, **56:**751-759.

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