Effects of dietary fiber on structure formation in bread during baking process

Annalisa Romano\textsuperscript{a}, Elena Torriera\textsuperscript{ab}, Paolo Masi\textsuperscript{ab}, Silvana Cavella\textsuperscript{ab}

\textsuperscript{a}CAISIAL-Centre of Food Innovation and Development in the Food Industry -University of Naples Federico II – Naples, Italy (annalisa.romano@unina.it)
\textsuperscript{b}Department of Food Science -University of Naples Federico II –Naples, Italy

ABSTRACT

The link between the intake of dietary fiber (DF) and health benefits has prompted the interest in fiber-enriched foods such as fiber-enriched baked goods. A distinction is established between insoluble DF and soluble DF. Insoluble and soluble forms of DF have different compositions resulting in different of nutritional, physiological and technological properties. In this work, the effect of insoluble and soluble fraction of different dietary fiber (coffee silverskin and inulin) on dough rheological behavior, leavening and baking performance was studied. Dough prepared from wheat flour containing two type of fibers were submitted to a lubricated squeezing test and to dynamic oscillatory measurements. Bubble evolution during leavening and baking phases was studied by measuring the variation in time of the total volume of the sample by means of Image Analysis. A dough without fiber was used as a control. Experimental evidence of the different behaviour of the dough and bread obtained with fibers are presented and discussed. It was proved that DF incorporation into wheat dough greatly interferes with protein association and its further aggregation during heating. In general, the addition of insoluble fibers causes the dough’s strength to increase. A negative effect of fibers on leavening and baking is observed. The experimental evidence suggests that the functional role of fibers in bubble evolution depend on DF type. Results from macrostructure analysis agree with those of rheological measurements.

Keywords: dietary fiber; rheological properties; image analysis; dough; bakery products

INTRODUCTION

Dietary fiber (DF) was reported to have many physiological benefits related to “western diseases” such as coronary heart disease, obesity, colon cancer and diabetes [1, 2]. DFs are defined as carbohydrate polymers with a degree of polymerization not lower than three, which are neither digested nor absorbed in the small intestine [3]. Total dietary fiber is the analytical term for DF that includes both water-insoluble and water-soluble dietary fiber. Insoluble and soluble forms of DF have different structural and chemical compositions resulting in different of nutritional, physiological and technological properties [4]. Several authors have demonstrated that the consumption of soluble DF can significantly reduce blood cholesterol and help stabilize blood glucose levels [5, 6], while consumption of insoluble DF helps to protect against colon cancer and other bowel disorders of the intestinal tract [7, 8]. A daily intake of approximately 30g is encouraged to promote health benefits associated with fiber. However, fiber intake is commonly lower than the recommended one, as consequence the development of foods with high fiber content should be desirable. Cereals represent the quantitatively most important source of DF. The practical application of different kinds of fiber materials in bread production has been widely studied, but a detrimental effect on dough handling and bread quality has been proved [9, 10, 11, 12]. The main problems of adding DFs for baking are a major reduction in loaf volume and a neglected effect on the final bread texture. Such deficiencies increase with higher levels of wheat flour substitution by fibre and depended greatly on DF properties. Coffee is one of the major food commodity and coffee by-products are amply available. The coffee silverskin (CS) is a tegument of coffee beans and constitutes a by-product of the roasting procedure. A previous study showed that CS displays the typical features of a potential prebiotic ingredient [13], because it has a high amount of DF with an absolutely relevant amount of soluble DF and it has a marked antioxidant activity due to the peculiar composition of its fiber, which is rich in Maillard reaction products and maintains some phenolic compounds. Whereas inulin is a soluble DF composed of a blend of fructose polymers extracted from plants with a degree of polymerization ranging from 2 to 60 [14]. Recently, research attention has focussed on the use of soluble DFs such as inulin type fructans [15, 16, 17]. The aim of this work was to evaluate the potential use of two DFs (coffee silverskin and inulin) at elevated content (9.8 %) as ingredient in breadmaking. The effects of DFs on dough rheological behaviour, leavening...
and baking performance were studied by means of rheological characterization of the dough behaviour and Image Analysis.

MATERIALS & METHODS

Materials
Samples were prepared by using: soft wheat flour (Barilla “00”, Italy), deionised water and different Dfs: CS-coffee silverskin (54% insoluble fiber; Illy Caffè, Italy) and LI- long chain (with DP minimum 23) inulin (98% soluble fibre; Chimab, Italy).

Dough-making procedure
All doughs were prepared in a Brabender farinograph (Duisburg, Germany), equipped with a 50 g bowl, by mixing soft wheat flour, deionised water, salt (1.25 g), sugar (0.5 g) and compressed yeast (0.75 g). For all samples, the water/dry matter ratio was kept constant and equal to 0.76. The dietary fiber concentration investigated was 9.8% (w/w). Doughs were mixed until their optimal development (previously investigated) and temperature were kept constant and equal to 25°C.

Lubricated squeezing test
Samples were compressed between lubricated parallel plates (diameter =40 mm) by means of an Instron Universal Testing Machine (Instron Ltd., mod. 4467 High Wycombe, GB), equipped with a 1kN load cell. Cylindrical samples (R₀=20mm; h₀=16mm) were compressed to a final height equal to 20% of the initial height at a crosshead speed of 10 mm/min. The deformation force was recorded as a function of time. Stress-strain curves for biaxial extensional flow were derived according to [18]:

\[ \varepsilon_b = -\frac{1}{2} \ln \left( \frac{h_t}{h_0} \right) \]

\[ \sigma_b = \frac{F_t \cdot h_t}{\pi \cdot R_0^2 \cdot h_0} \]

where \( h_0 \) and \( R_0 \) are the initial height and radius of the sample; \( F_t \) and \( h_t \) are the force and height at time \( t \). Tests were carried out in triplicate and average values were reported.

Dynamic mechanic analysis
Dynamic mechanic measurements were carried out by means of a strain controlled rheometer (ARES-LS, Rheometrics Inc. Piscataway, NY), equipped with parallel-plate geometry (50 mm plate diameter) and a Peltier heating system. Dough was placed between the plates and the gap adjusted to 2 mm. All measurements were performed in oscillatory mode. Temperature ramp tests were performed between 10 and 90°C, at a heating rate of 1°C/min, at a fixed frequency of 1 rad/s with a small enough oscillation amplitude (0.1%) to ensure linear viscoelasticity. During tests the storage modulus (\( G' \)) as a function of temperature was monitored. All data represent the mean of at least three independent measurements.

Image Analysis
45 g of dough were taken just after mixing and placed on a flat surface where it could expand in every directions without constrains during leavening and baking processes. The dough was incubated at 36 ± 1°C, 70% U.R., for a time corresponding to the maximum volume of the dough (data not shown). Baking took place inside a conventional electric oven (Moretti Forni S.p.A., Pesaro, Italy) where temperature was kept under control at 180°C for 30 min. Sample was continuously photographed with a digital camera (Canon INC, Japan) during leavening and baking processes. By assuming axial symmetry, the loaf was interpreted as a solid of revolution generated by the revolution of a lamina around the symmetry axis, and its volume \( V \) was calculated using the following formula:

\[ V = 2 \pi A r_g \]

where \( A \) is the lamina surface and \( r_g \) the distance of the center of the mass of the lamina from the axis. The area and centre of the mass were determined by a computer assisted image analyser (Jandel Sigma Scan® Pro Version 2.0, Jandel Corporation, 1995). Each value represents the mean of 3-7 independent measurements.
**Statistical analysis**

Analysis of variance (SPSS v11.0) was performed in order to evaluate the effect of DFs on volume expansion ratio. Significant differences between the treatment means were compared by means of Duncan’s multiple comparison test at the 95% confidence level ($p \leq 0.05$).

**RESULTS & DISCUSSION**

*Effect of dietary fiber on biaxial extensional properties*

Leavening and baking stages of breadmaking are characterized by fast biaxial expansion of gas cells [19]. The walls of the expanding gas cells are subjected to a biaxial extensional flow: the extensional strain is large while the strain rate is low. The effect of DFs on biaxial extensional properties of wheat flour doughs was investigated, the experimental results are displayed in Figure 1.

For all cases detected, the curves can be divided into three sections: pre-yield, yield and strain hardening [20]. The CS and LI doughs have a higher yield stress and a higher resistance to flow compared to control. When a fiber is added to dough less water could be available for protein molecules to develop gluten network in dough. Moreover, formation of gluten matrix is hindered because the fibre molecules obstruct the flour proteins from coming together and a resistance to flow associated with the presence of fiber particles can be supposed. The results reported (Fig. 1) illustrate that the control dough shows the lowest strain hardening, while CS has a greater effect than LI.

*Effect of dietary fiber on rheological properties*

Figure 2 shows the $G'/G'_0$ ratio of control, LI and CS dough during a temperature ramp. From 10 to about 30°C, control and CS dough present the same behaviour: $G'/G'_0$ gradually decreases as the temperature increases as a consequence of the softening of the dough.

As the temperature increases above 30-40°C, $G'/G'_0$ increases and reaches a maximum value between 70-75°C. The increase of the elastic module is mainly due to starch gelatinization. The shape of the curve does not change when CS is added; however the presence of the fiber has a remarkable effect on the value of $G'/G'_0$. The water-holding capacity of CS reduces the liquid water for starch, so the temperature at which irreversible phenomena begins is higher for CS dough and the $G'/G'_0$ increment is lower than control. Similar results were moreover reported for dough prepared with different water content [21].

At the highest temperature, the $G'/G'_0$ values of dough decrease slowly.

The behaviour of LI is different during temperature ramp: the increment in $G'/G'_0$ caused by addition of inulin seems to be due both the formation a gel and starch gelatinization.
Both thickening property and capability of LI to delay starch gelatinisation during heating have been recognised by several authors [11, 17]. $G'/G'_{0}$ value of LI reaches a maximum value between 75-80°C and it remains roughly constant with further increase in temperature.

![Figure 2](image)

**Figure 2.** $G'/G'_{0}$ as a function of temperature for control (○), LI (●) and CS (△) dough

**Effect of dietary fiber on leavening and baking processes**

Figure 3 shows the volume expansion ratio (volume at time t / initial volume) in time of control, LI and CS sample during leavening and baking processes.

The addition of DFs had an effect on kinetic of leavening as compared to the control dough (fig. 3a). The volume expansion ratio of LI is the lowest (p<0.05) and equal to 1.7 (fig. 3b). The time to reach the maximum dough development of control (60 min) was reduced by the addition of LI (25 min). Probably, the interactions between flour proteins (gluten) and these fibres prevent the free expansion of wheat dough during the leavening stage. This result is confirmed by [15], who found that fermentations of dough containing inulin need less time to reach the maximum than does the control. The leavening period for the CS-containing dough is longer than for control (75 min), because the maximum volume is reached in a longer time (fig. 3c).

The experimental results can be interpreted both in terms of strain hardening and the chemical composition of fibre added. Strain hardening has been shown to be necessary for stability in any operation which requires large extensions, such as the expansion of gas cells during bread dough processing [20, 22]. The different effect on strain hardening behaviour presented by DFs justifies the differences in the volume at the end of the leavening.

During the first minutes of baking a typical oven rise phenomenon is observed, the loaf volume reaches a maximum value which is affected by fiber type. LI dough shows the highest increment volume during oven rise. In fact LI is a fructo-oligosaccharide and influences thermo-mechanical properties of dough (fig. 2) which results softer and less resistant to gas expansion than other samples.

The formation of the sponge-like structure that characterizes bread is completed during the first 10 min of baking. The addition of DFs slightly reduced the final volume of bread. The lower final volume is obtained for CS added (1.9). Several authors [23, 24] found that the addition of particulate components, especially bran and epicarp fibres, to dough promoted a physical disruption of the gluten protein matrix. They explained this by assuming that fibres act as points of weakness or stress concentrations within the expanding dough cell walls. The current work supports this suggestion.
CONCLUSIONS

Flour replacement at elevated levels by DFs changes rheological behaviour of dough and breadmaking performances. Experimental evidence shows that the addition of DFs causes a higher resistance to flow and strain hardening of doughs. The results prove that when DFs are added to the dough, they interact with water, reducing the liquid water for starch. When CS is added, this phenomenon is related to a decrease in the water ability due to increased fiber-water interaction. While the behaviour of doughs with inulin may be attributed to gel-forming property and capability of inulin to delay starch gelatinisation during heating.

A negative effect of fibres on volume ratio is observed during breadmaking. LI dough shows the minimum increment volume during leavening, with the fermentation time being shorter. The different effect on rheological behaviour presented by DFs justifies the differences in the volume at the end of the leavening. The incorporation of LI determines a pronounced oven rise, but the maximum volume increment of the baked bread corresponds to the control dough. The minimum final volume is obtained for CS added.

Results both dough rheology and bread properties drive on to conclude that the functional role of a high amount of DF on structure formation in bread during baking process greatly depends on fiber source.
REFERENCES


