Effects of adding cellulose on rheological characteristics of wheat flour dough and on bread quality

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Abstract

Several studies have associated the consumption of dietary fibre with positive health effects and as a result a wide array of fibre ingredients has been developed to be included as part of formulation of functional food. Powdered cellulose is one type of fibre ingredient that is finding wide application in food, mainly in functional bread, either to increase level of fibre or to reduce calorific value. However, the inclusion of fibre in a formulation will inevitably bring about certain changes to the product. This current study investigated the effects of adding different levels (2, 4 and 6 %) of powdered cellulose on the rheological properties of wheat dough and bread qualities. The main dough characteristics assessed were farinograph water absorption, resistance and extensibility; while bread was evaluated for volume, weight, crumb softness and nutritional values (level of insoluble dietary fibre and calorie content). The bread qualities of cellulose-added bread were compared to those of brown bread. Findings revealed that water absorption of the dough and its stability against over-mixing increased significantly ($P<0.05$) with increasing level of powdered cellulose. Although the dough became more resistant, it lost extensibility; and thus bread of smaller volume was observed, with a decrease of about 200 cm3 at 6 % level cellulose, compared to plain bread. Cellulose-added bread was slightly heavier than plain bread and brown bread by about 5 – 15 grams. At 4 and 6 % level of fibre, bread had softer crumbs compared to both plain white bread and brown bread. With 6 % cellulose, the level of insoluble dietary fibre was 13.8 %, as compared to 6 % in plain bread and 13.1 %

in brown bread. At 6 % cellulose there was a decrease of 77kcal and 47kcal compared to plain and brown bread respectively. Addition of cellulose at 2 and 4% gave bread with larger volume without improving the nutritional characteristics. At 6 % level of cellulose, bread had almost same level of insoluble dietary fibre than that of brown bread, but still offering better quality in terms of volume, weight, colour and texture compared to the brown bread. Therefore addition of powdered cellulose at level 6 % was found to be most appropriate for the purpose of functional bread.

Keywords: Cellulose, rheology, flour, bread, insoluble fibre, calorie

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INTRODUCTION

Dietary fibre constitutes that part of carbohydrates that cannot be digested by the human stomach (IFST, 2001). Examples of dietary fibres are cellulose, hemicelluloses, pectin or lignin. Although it remains undigested, several studies have proved that dietary fibre is particularly of great importance in prevention or attenuation of diseases such as constipation (Izydorczyk *et al.*, 2005), coronary heart diseases (AACC, 2001) and diabetes (Leeds *et al.*, 1998). The positive images that are associated with dietary fibre have encouraged many scientists to do further investigations on it.

As a result of the rising concern about maintaining good health, food processors have recently been filling the supermarket shelves with functional foods designed to help fight against diseases that are associated with modern lifestyle, such as diabetes and obesity. Since it has been shown that consumption of dietary fibre is providing relief from these non-communicable diseases, food technologists are exploiting this component. Thus, dietary fibres are being extracted from different plants and are finding applications as food ingredient in many products (Bahr, 1996).

Cereals, like flour, are an important source of dietary fibre (Wang *et al*., 2002). But with modern milling techniques that are used for processing white flour, most of the bran gets lost. Bran contains the highest proportion of dietary fibre; therefore bread baked from white flour has a lower level of dietary fibre than brown bread (Fox & Cameron, 1995). Bread is the most commonly consumed cereal (Symons *et al.*, 2004); hence it can be made a possible target to promote the health benefits linked with dietary fibre. The simplest way to increase dietary fibre level of bread is to partly substitute white flour with whole wheat flour. Grains such as oat, barley, millet and rye can also be added; but using these grains as sources of fibre has some shortcomings; the resulting bread usually does not have a nice and attractive appearance, and moreover, does not offer appealing taste (Waring, 1998). With the advent of newer technologies and more advanced knowledge, new fibre ingredients have been developed and they are almost undetected in bread (Berry, 2004).

Powdered cellulose is a commonly used fibre ingredient. Cellulose is an insoluble dietary fibre of white colour, with no specific taste and odour. Powdered cellulose can be considered as the purest form of insoluble fibre, as it consists of 97 % cellulose (Ang *et al.*, 2005). However, depending on the level of purity, powdered cellulose comprising of 100 % cellulose can be obtained; thus its addition at only low level will result in products having high-fibre content. Cellulose is a linear molecule with protruding hydroxyl groups. The presence of hydroxyl groups encourages hydrogen bondings with water molecules, thus cellulose is able to absorb large amount of water (Belitz *et al.*, 2004). Due to the properties of cellulose, when it is added to bread formulation, it often results in changes in the rheological properties of wheat dough and impacting on bread quality. Briefly these changes can be: increase in water absorption of the dough; weakening of the dough; lower processing tolerance, and decreased loaf volume (Lallemand Inc., 1997). As a consequence of the negative effects, it is therefore recommended that when more than 10 % of fibre is added, the bread formula has to be modified extensively (Stear, 1990). Flour having high protein content or additives such as vital-gluten could be used, so that stronger dough is obtained, thereby good quality bread is made.

Another reason of adding dietary fibre to bread is to reduce its calorie content (Ang *et al.*, 2005). Cellulose does not contribute to any calorie and is often used in low-calorie foods as it has a bulking effect (Ang *et al.*, 2005). For the purpose of low-calorie bread, approximately 20 % of cellulose should be added (Lallemand Inc., 1997); but the presence of such a high level may disturb the dough system, due to the physical and chemical properties of cellulose. Therefore when aiming for a significantly large reduction in calories, powdered cellulose should be used together with other low-calorie ingredients such as gums to compensate the negative effects (Stear, 1990).

Although dietary guidelines advise on the consumption of bran-added bread, commonly known as brown bread, it is not very popular. The presence of bran in bread does not give an appealing colour, texture and taste to the consumers; thus the reason for its low consumption despite its high fibre content. This study therefore investigates into the potential of adding powdered cellulose to white bread as an alternative way to increase the level of dietary fibre, more precisely insoluble fibre. In this approach, the nutritional profile of white bread enriched with cellulose, can become comparable to that of brown bread while providing more desirable quality, in terms of taste and colour.

Therefore, the main objectives of the current study were to investigate the effects of adding powdered cellulose at different levels on the rheological characteristics of dough and on bread quality. Dough quality involved farinograph and extensigraph properties, while bread quality was evaluated in terms of volume, weight, crumb softness and nutritional values especially insoluble dietary fibre and calorie content. The quality of cellulose-bread was also compared to that of brown bread.

METHODOLOGY

Materials

White flour (13.9 % moisture, 11.9 % protein and 0.6 % ash) used contained added regulators, such as calcium carbonate, ascorbic acid, *L-cysteine* and fungal *amylase*. Brown flour was made of white flour mixed with coarse bran particles (14.6%) during the production process. Both types of flour are used mainly for bread making in local bakeries. Powdered cellulose was purchased from NB Entrepreneurs [1](India). It is a white, crystalline and odourless powder. It is also insoluble in water and has a pH in the range of 6.4. It consists of 100 % pure cellulose, with no added starch. Instant dry yeast (*Saccharomyces cerevisiae*) was used.

[1] Website: www.nbent.com

Treatments

The treatments consisted of substituting white flour with powdered cellulose at levels 0, 2, 4 and 6 %. The levels of cellulose chosen were based on findings from literature, whereby addition of more than 10 % of fibre necessitates the use of additives. Since the main objectives of the current study were to investigate the real effects of cellulose on dough and bread qualities, therefore addition levels lower than 10 % were chosen. It was also found that for the purpose of high-fibre bread, fibre can be added at level between 1 – 4 %. The powdered cellulose that was used, consisted of 100 % pure cellulose, and thus addition at 2, 4 and 6 % level was considered to be most appropriate to produce bread which can have high fibre content. Brown flour was used for bake trials to assess bread quality only.

Methods

Dough properties

The effect of powdered cellulose on dough properties during mixing was determined by the Brabender Farinograph, following the AACC Approved methods (54 – 21, 1983). The parameters determined were: percentage water absorption (% WA) of flour to form standard dough with consistency 500 Brabender Unit (BU), dough development time (DDT) that is the time taken to form the dough, dough stability (DS) and fall-off time (FOT) which indicate the strength of dough.

The rheological properties of dough was determined by the Brabender Extensigraph, following the AACC Approved methods (54 – 10, 1983). The main parameters assessed were resistance (R) of dough to stretching, extensibility (E) which is the extent to which the dough will stretch before tearing, and the Resistance to Extension (R/E) ratio used to evaluate the overall strength of dough.

Baking tests

The Straight Dough (Bulk Fermentation) method was used. A typical baker's bread formula[2] was used and consisted of 100 g flour, 1.5 g salt, 0.8 g yeast, the amount of water added (in grams) was obtained from farinograph water absorption results. Dough was divided into 500 ± 0.1 g pieces, placed in loaf pan, proofed for 90 minutes at 30 ˚C and 90 % relative humidity. Bread was baked at a temperature of 250 ˚C for 25 minutes. Bread quality was evaluated after cooling for 2 hours on a wired rack.

Evaluation of bread quality

After cooling, bread was weighed and the volume was determined by the Rapeseed Displacement method. The volume is obtained by multiplying the weight of the displaced rapeseed by the density of the seed (0.7cm^3/ gram). Textural evaluation of the crumb was carried out on the basis of elasticity and firmness, by pressing on the crumb surface gently with the finger tip, and giving rating of "Less Soft",

[2] Bread Formula used by most bakers in Mauritius.

"Soft" and "Very Soft". The bread from treatment 0 % cellulose (Blank) was taken as reference and given rating of "Soft".

As a requirement for the determination of nutritive value, bread samples were prepared according to Standard AOAC Official Method 926.04 (1995). The level of insoluble fibre in the bread samples was determined according to the Total Dietary Fibre – Rapid Gravimetric Method (AACC 32-06). The procedure for the determination of insoluble fibre was followed, whereby a neutral detergent solution was used and *α-amylase* enzyme was added to digest starch so as to prevent gelatinisation. The Tecator Fibretec equipment was used to carry out the determinations.

The calorie content of bread samples was determined by the Oxygen Bomb calorimeter according to Manual No. 130 Oxygen Bomb Calorimetry and Combustion Methods.

Statistical Analysis and Design

The basic structure of the experiment was a randomised block design with four blocks according to days. The treatments consisted of substituting white flour with powdered cellulose at levels 0, 2, 4 and 6 %. Different parameters of dough quality (farinograph measurements, dough extensibility and resistance) were evaluated for each treatment. Bread obtained from all the treatments, including brown bread were assessed for volume, weight, crumb texture and softness; and nutritive value (insoluble fibre and calorie content). Each parameter observed was assessed in duplicates, except for bread quality (volume, weight and crumb softness), which was performed in triplicates.

All statistical analyses were carried out using MS EXCEL for WINDOWS. Since the treatments (0, 2, 4 and 6 %) included a quantitative variable, that is addition of cellulose at increasing levels, therefore a simple linear regression analysis was more appropriate to analyse the different parameters (Chew, 1980).

RESULTS AND DISCUSSION

Dough characteristics

Effect of cellulose on farinograph parameters

The water absorption (WA) capacity of a particular flour is of considerable importance in the bread industry. This parameter contributes in producing dough that has a good consistency for both kneading and moulding (Bread Research Institute, 1989). The addition of powdered cellulose resulted in a significant increase ($P<0.05$) in % WA capacity of dough (Figure 1). The linear increase observed between the % cellulose and WA indicates that the dough might continue to absorb more water as higher levels of cellulose would be added.

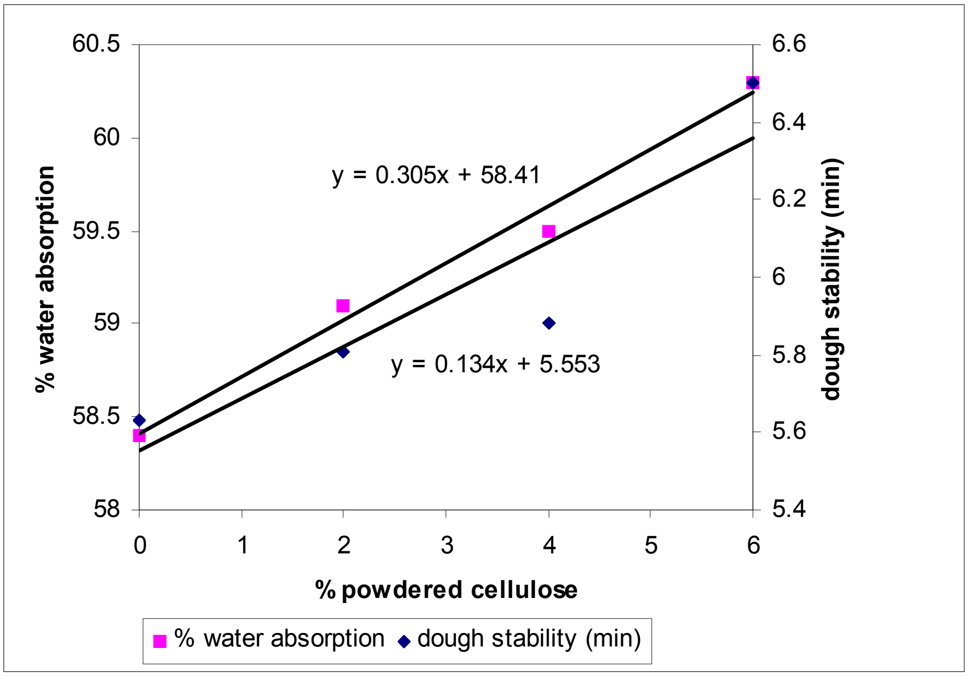

Figure 1. *Effect of adding powdered cellulose on % water absorption and dough stability of flour*

Similar effects had been observed in several studies. Gomez *et al.* (2003) reported an increase of 1.7 % in WA when flour was substituted by 2 % microcrystalline cellulose. However, the rise in WA is relatively higher compared to the current findings where an increase of only 0.7 % had been observed with same level (2%) of cellulose. Microcrystalline cellulose is a depolymerised form of cellulose (Organic Materials Research Institute, 2001). The length of the cellulose particles may also account for the different % WA obtained during the two studies, whereby coarse fibre tends to absorb more water than fibre of finer particle size (Ang *et al.*, 2005). The ability of cellulose to absorb water is explained by its chemical structure as the presence of hydroxyl groups makes cellulose a hydrophilic polymer. Therefore, the hydroxyl groups allow more interactions with water molecules, through hydrogen bonding (Wang *et al.*, 2002) and WA tends to increase. Moreover the presence of other components in the dough, such as wheat proteins may alter the hydration behaviour of fibre (Rosell *et al.*, 2005). The flour that was used during the study contained regulators and these might have influenced the WA capacity of dough, alongside the effects of cellulose. When 6 % of powdered cellulose was added, the WA increased by 1.9 %, with respect to the blank (0 %). Usually, if a particular flour absorbs more water, it is considered to be economical as the yield of the dough and ultimately that of bread increases (BRI, 1989). In the study, an increase in amount of dough was noted when higher levels of cellulose were added. Such property is considered as desirable by many bakers, as it contributes to more profit (BRI, 1989). Water is an essential ingredient in bread dough. It participates in hydration of gluten, thereby ensuring expansion of the dough and retention of carbon dioxide. Some other roles of water include starch gelatinisation, and the development of colour and flavour (Rosell *et al.*, 2005).

However, the presence of an excessive amount of water results in an imbalance in the dough system. Since fibre has the property of retaining water, the resulting 'fibre-added' bread has high moisture content (Burrington, 1998); although this will contribute to extend shelf-life of bread by retarding staling, the product becomes more susceptible to spoilage by moulds. Therefore fibre-enriched bread may necessitate the addition of antimicrobial agents such as calcium propionate so as to preserve its keeping quality and safety (Lallemand Inc., 1997).

Dough development time (DDT) indicates the time taken to form dough of an appropriate consistency. DDT for blank was 1.9 minutes with standard deviation, 0.1 minute. The addition of different levels of cellulose did not cause any significant change ($P>0.05$) in the DDT. This result can be confirmed by another study whereby fibre added at 3 % level, did not cause any effect on DDT (Wang *et al.*, 2002). But, according to Stear (1990), the presence of fibre in dough increases mixing time until the dough reaches optimum consistency. Moreover, fibre is also resistant to mechanical damage (Vadhera *et al.*, 2004), thus resulting in higher DDT. But, the source and composition of the fibre influence the mixing properties, such that fibre of smaller size causes a decrease in DDT (Gomez *et al.*, 2003). Thus, the powdered cellulose used was probably of small size and there was a counteracting effect thereby resulting in no effect on the DDT.

Dough stability (DS) indicates the capacity of the dough to resist to fermentation and processing changes. A significant linear increase in DS ($P<0.05$) was observed (Figure 1). Gomez *et al.* (2003) stated that the addition of fibre in wheat dough has always caused an increase in the stability of the dough, independent of the source and composition of fibre that is used. This can be explained by the formation of hydrogen bonds between hydroxyl groups and water molecules which are retained strongly to each other, therefore increasing the stability of the dough.

Fall-Off time (FOT), also referred to as degree of softening, determines the stability of the dough over time. The addition of 6 % powdered cellulose caused an increase of 3.8 BU (Brabender Unit) with respect to the blank; however, the increase was not significant ($P>0.05$). Cellulose is quite resistant to mechanical damage, thus explaining the ability of the dough to maintain its strength although there is over-mixing.

Effect of cellulose on extensigraph parameters

Resistance indicates the strength of dough. When flour was substituted with cellulose, a highly significant increase ($P<0.01$) was noted in resistance of dough (Figure 2). Gomez *et al*. (2003) reported an increase in resistance of dough with addition of fibres. Many studies discussed that the interactions between the chemical structure of the fibre and the wheat proteins could be responsible for the increase in resistance (Wang *et al.*, 2002). At 6 % level of cellulose, the resistance of the dough increased and this result is in agreement with the high dough stability obtained from the Farinograph. With 6 % cellulose, resistance of dough increased by 105 BU with respect to blank (0 %). From the regression equation, for every 1 % level of cellulose that would be added, resistance of dough is expected to increase by 18.2 BU.

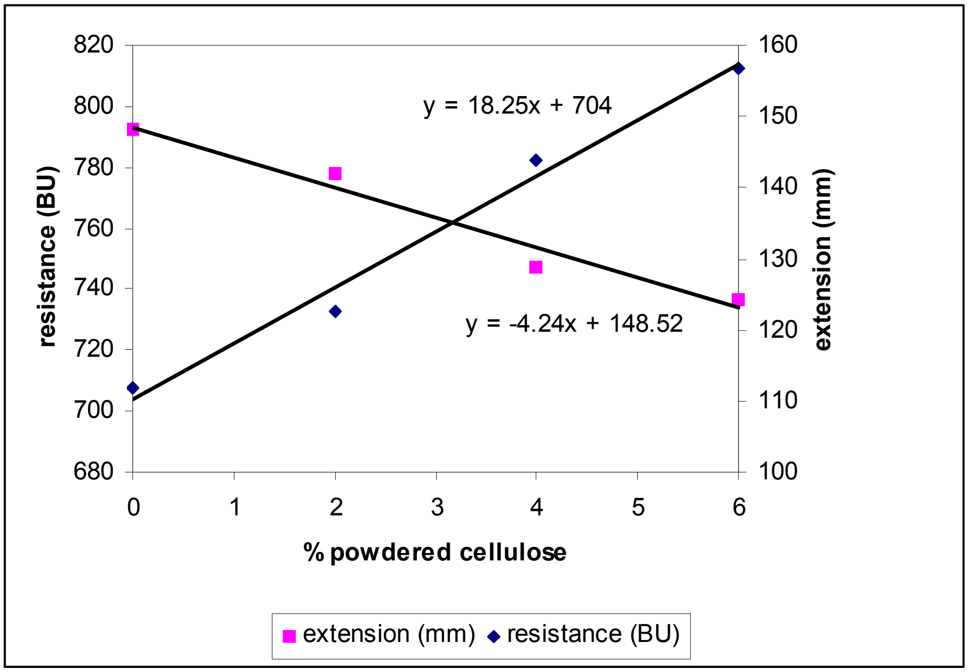

Figure 2. Effect of adding powdered cellulose on the extension and resistance of flour

Extension is the degree to which dough can be stretched before tearing. As higher levels of cellulose were added, the extensibility of dough decreased significantly ($P<0.05$), implying a decrease in the stretching ability of dough (Figure 2).

Wang *et al.* (2002) had reported similar effects when different types of fibres were substituted in wheat dough. The degree of stretching of particular dough is determined by both the quality and quantity of gluten in flour (BRI, 1989). Gluten is formed by the hydration of wheat proteins and it contributes to elasticity. But when flour is substituted by powdered cellulose, the protein content decreases and as a consequence, the dough loses part of its extensibility property. A more considerable decrease in stretching was observed when 4 and 6 % cellulose were added compared to blank (0 %). It is expected that extensibility of dough would decrease by 4.3 mm for each 1 % level of cellulose added. Thus, if cellulose will be added at higher levels, it may be necessary to use flour of high protein content, about 16 % (Stear, 1990). It is also recommended to add oxidants such as ascorbic acid or calcium peroxide so as to increase strength and elasticity of the gluten structure (Lallemand Inc., 1997). When fibre is added, the dough increases its demand for water and this results in dilution of gluten and hence the structure of the protein network is weakened resulting in reduced extensibility of the dough. Therefore, the decrease in extensibility which occurred with 6 % level of cellulose could be explained by the increase in water absorption capacity of flour. Vital wheat gluten may be added to compensate the negative effects (Lallemand Inc., 1997).

The R/E ratio is calculated by dividing resistance by extension, and it relates to the overall strength of dough. Higher R/E ratio indicates stronger dough (Rasper *et al.*, 1991).

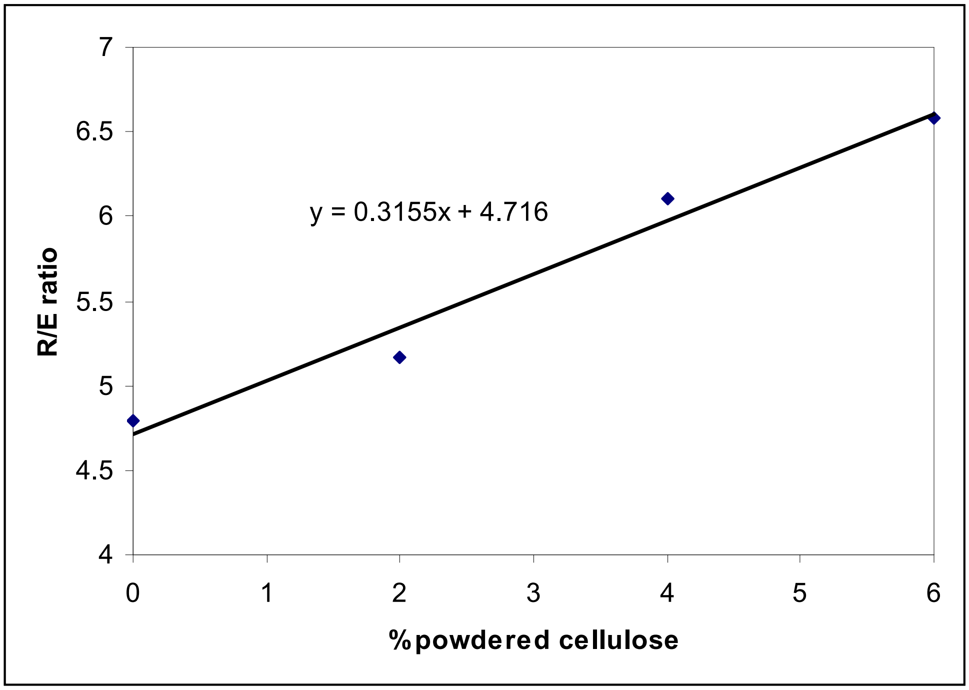

Figure 3. Effect of adding powdered cellulose on the R/E ratio

When cellulose was added at higher levels, R/E ratio increased significantly from 4.8 (0% cellulose) to 6.58 (6% cellulose) ($P<0.05$) (Figure 3). The increase in R/E ratio could be attributed to the presence of hydroxyl groups that are formed. The addition of cellulose decreased extensibility, consequently leading to an increase in the R/E ratio thus implying that addition of cellulose improved the overall strength of dough.

Bread quality

Quality of bread is determined by the rheological properties of dough, and thus changes in the characteristics of dough will eventually affect quality of the final bread.

Volume

Bread with high volume is more desirable to consumers (Khedu, 2005). When cellulose was added at different levels, the rapeseed measurements showed that the volume of the resulting breads decreased significantly ($P<0.05$) (Table 1). The reduction in volume of loaf is in agreement with findings from other studies whereby different types of fibres had been added to bread (Park *et al.*, 1997 & Wang *et al.*, 2002). During the fermentation process, as carbon dioxide gas gets accumulated, the cell walls of the dough expand in size, thus the volume of the baked bread will depend on the degree of extension of gluten and the ability to retain maximum gas (BRI, 1989). But when cellulose fibre is added, the flour proteins interact with hydroxyl groups on the cellulose molecules and these interactions interfere with the free expansion of wheat dough during the proofing stage (Gomez *et al.*, 2003); similarly, a reduction in extensibility of dough was observed in the current study. Furthermore, a study on the fermentation behaviour of fibre-added dough showed that presence of fibre contributed to the greatest loss in volume and this effect was supported by the fact that the dough had an increased permeability to carbon dioxide gas, therefore less gas was retained within the cells structure (Wang *et al.*, 2002). Reduction in loaf volume can be attributed to the presence of a large amount of water in the dough which causes the premature gelatinisation of starch, thereby solidifying the structure and as a result the oven-spring occurred slightly (Park *et al.*, 1997). The highest decrease in volume was observed when flour was substituted with 6 % of powdered cellulose. Brown bread gave a volume of 1797 cm^3 (Table 1), and although cellulose caused an overall reduction in volume, bread enriched with 6 % cellulose, still gave a higher volume of 2132 cm^3 than the brown bread. Since volume is an important parameter that determines consumer acceptability, there have been several proposals to improve the volume of fibre-enriched bread. The gluten network can be reinforced by increasing the protein level of flour; this was successfully demonstrated with the addition of vital wheat gluten (Park *et al.*, 1997). Some studies have also investigated the potential of hydrocolloids, namely hydroxypropylmethylcellulose (HPMC), to improve bread volume. When HPMC was added at only 0.5 % level, the volume of bread increased considerably (Rosell *et al.*, 2001 & Barcenas *et al.*, 2005). Besides the contribution of additives, volume can also be improved by modifying the processing conditions, such as reducing fermentation time so as to minimise the weakening effect that fibre has on dough's structure (Lallemand Inc., 1997).

Treatment	Volume/ cm^3	Weight/ g	Crumb Quality	IDF Content / %	Calorie Content / kcal per 100g bread
0 % cellulose (plain white bread)	2332±24	427±1.9	Soft	6.3±0.2	8129±10
2 % cellulose	2262±28	433±1.8	Soft	8.9±0.2	8111±15
4% cellulose	2177±20	438±2.4	Very Soft	10.1±0.1	8079±27
6% cellulose	2132±27	441±1.1	Very Soft	13.8±0.2	8052±25
Brown bread	1797±25	436±3.3	Less Soft	13.2 ± 0.2	8099±11

Table 1: Effects of cellulose on quality of bread (mean ± SD of four independent determinations)

Weight

Weight of loaf is an important parameter which is controlled by the regulations. Addition of cellulose caused a significant increase (P<0.05) in the weight of bread (Table 1). An increase of 14 g was observed when 6 % level of powdered cellulose was added. The structure of cellulose can again be used to explain this increasing trend. The hydroxyl groups retain water molecules, which can be confirmed by the high moisture content reported when fibre was added to bread (Wang *et al.*, 2002). The weight of brown bread was found to be 436 g and this was significantly higher (P<0.05) than plain bread. Although bread that contained 2 % cellulose was lighter than brown bread, the difference was not significant (P>0.05). However, bread with 4 and 6 % cellulose were heavier than brown bread by 2 g and 5 g respectively. Although weight contributes to adding value to bread (Mewhoor, 2005), whereby lighter bread is rejected by consumers, the inclusion of cellulose in wheat dough slightly increased the final weight of bread by only a few grams, thus it can be inferred that cellulose did not contribute to adding extra value in terms of weight to bread.

Crumb Quality

“Soft” and “very soft” crumb are desired by consumers. When cellulose was added at 2 %, the crumb of bread had similar softness as blank (0 %). However, softer crumbs were observed with 4 and 6 % level of cellulose (Table 1). The present findings can be confirmed in a study performed using pea fibre (Wang *et al.*, 2002). Pea fibre contains a large proportion of cellulose. Softer crumbs may be due to additional water that is retained within the cellulose matrix. Brown bread gave less soft crumb, which could be due to the presence of bran particles.

Nutritive value of bread

Insoluble dietary fibre (IDF)

Insoluble dietary fibre contributes to many health benefits. Since powdered cellulose is an example of insoluble fibre, when it is added to bread, it resulted in a highly significant increase (P<0.01) in the level of IDF (Table 1). This rise in fibre can be justified as the powdered cellulose that was used was composed of 100 % cellulose, an insoluble fibre. Brown bread was found to contain 13.2 % of IDF, that is, almost twice the amount present in plain white bread (blank), which contained 6.3 %. When 2 and 4 % of cellulose were added respectively, although the level of IDF increased significantly (P<0.05), it was still lower than that of brown bread. At 6 % addition, bread contained twice the level of IDF than plain white bread and almost same level as brown bread. The main insoluble fibres that were determined through the Neutral detergent method include mainly cellulose, hemicelluloses and lignin (Perstorp Analytical, 1995). This particular method was previously used by Vadhera *et al.* (2004) to characterise the types of fibres present in different sources.

Calorie content

Excess calorie (kcal) contributes to weight gain. The addition of powdered cellulose caused a significant decrease (P<0.05) in the calorie content of bread (Table 1), with a decrease of 77 kcal noted with 6 % level of fibre. Powdered cellulose does not have any calorific value; therefore a reduction in calorie was expected since in the bread formulation, part of flour was substituted by powdered cellulose at different levels. The calorie contribution of 100 g of brown bread was found to be 8099 kcal. With the addition of cellulose, the calorie content of 100 gram of bread was lower than that of brown bread. When 4 and 6 % of cellulose were added, the calorie content of bread was significantly lower (P<0.05) than that of brown bread by 20 kcal and 47 kcal per 100 g of bread respectively. However, with such low levels of cellulose, the decrease in calorie is too small and therefore this cellulose-added bread cannot be promoted as an aid in slimming diets. Thus, to be able to give the bread a low-calorie claim, up to 20 % of fibre should have been added (Lallemand Inc., 1997). However when cellulose is added at 6 % level, there were already some negative effects such as, decreased extensibility of dough and reduced bread volume. Therefore when aiming for at least a 33 % reduction in calorie, the bread formula should be modified extensively and besides using cellulose, ingredients such as gums should also be added (Stear, 1990) and the new formula might not be accepted by small and medium-sized bakeries due to extra costs.

CONCLUSION

Addition of powdered cellulose caused a general improvement in all the parameters tested, except that extensibility of dough decreased, thereby resulting in a reduction in volume of bread. But in practice R/E ratio is mostly used to determine strength of dough, and with addition of cellulose, higher R/E values were obtained, thereby implying an overall increase in the strength of bread dough. Moreover, cellulose increased the level of insoluble dietary fibre of bread, and the weight of bread and also lowered the calorie content. The positive effects of adding cellulose outweighed the negative ones. At both 2 and 4 % level of cellulose, the overall dough and bread qualities (Table 1) were more desirable, but the aim of improving the nutritive profile of white bread, in terms of increased insoluble dietary fibre and decreased calorie content, was not achieved. With 6 % cellulose, bread was of smaller volume compared to plain white bread, but had softer crumb and improved nutritive value were obtained. White bread, enriched with 6% cellulose had higher volume, weight, level of IDF and more soft crumbs with respect to brown bread. Cellulose-bread contained only 47 kcal less than brown bread and 77 kcal less than plain white bread; therefore at such low level, the addition of cellulose did not have significant effect on the calorie content of bread. It can thereby be concluded that addition of cellulose at 6 % would be most appropriate for the purpose of functional bread, in the context of providing bread with higher level of fibre and yet with more appealing quality than brown bread. Moreover, the addition of cellulose did not at all alter the appearance of white bread, and its presence is almost undetected. In order for bread to be claimed as a low-calorie bread, more than 6 % cellulose should be added. Cellulose can also be an interesting ingredient for bakers to increase water absorption capacity of dough.

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