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Role of hydrocolloids in improving the physical and textural characteristics of fennel bread

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Abstract

Four different hydrocolloids, carageenan, carboxymethyl cellulose, guar gum and xanthan were administered at four different levels of substitution, 0.25, 0.5, 0.75 and 1.0% to 7.0% (w/w) fennel fortified bread to study the effects of hydrocolloids as texture improver. Physical properties like loaf weight were mostly unchanged while addition of hydrocolloid seems to have a positive effect on loaf volume. Crumb firming kinetics of the breads was investigated on storage using the Avrami model. Results seemed to suggest that application of hydrocolloids at lower levels slowed the firming kinetics. Crumb grain properties were studied using image analysis which suggested an increased number of cells and a lower average cell size for hydrocolloid substituted breads. Effect of hydrocolloids was further reasoned by an inverse relation between the specific volume and the average cell size of the bread samples. Rheological parameters such as G^* was seen to increase on hydrocolloid addition suggesting increased rigidity in the samples.

Introduction

Bread represents the most important part of the total daily food consumed. Hydrocolloids have specifically found a wide application as additives in bread formulations. The functional effects of hydrocolloids stem from their ability to modify dough or batter rheology and keeping qualities of finished baked products (Yaseen, 2010). Briefly, hydrocolloids are added to breads to modify texture (Rodge *et al*., 2012), control water absorption and consequently dough rheology (Mandala *et al*., 2007), improving their shelf life by keeping the moisture content and retarding the process of staling (Davidou *et al*., 1996; Rojas *et al*., 1999; Collar *et al*., 1999, Kohajdová and Karovičová, 2009). The final product has higher softness while maintaining longer shelf life (Azizi and Rao, 2004). The most generally considered mechanism suggests that hydrocolloids have a weakening effect on the starch structure causing a better water distribution and retention, and also a decrease in the crumb resistance (Armero and Collar, 1996; Guarda *et al*., 2004; Kohajdová and Karovičová, 2009). Additionally, hydrocolloids also influence the gluten network or create bonds in wheat flour dough and thus change its viscoelastic properties to produce breads with higher volumes, better porosity, desired crumb texture etc (Pečivová, 2011). In fact, guar gum, xanthan, arabic and locust bean gums, carrageenans, alginates, pectins and cellulose derivatives have been used to improve bread quality as per previous studies (Rosell, Rojas and Benedito de Barber, 2001; Sharadanand and Khan, 2003; Guarda *et al*., 2004). The cellulose derivatives (methylcellulose, carboxymethylcellulose and hydroxypropylmethylcellulose) are obtained by chemical modification of cellulose, which ensures their uniform properties, in opposition to the hydrocolloids from natural sources that have a high variability (Guarda *et al*., 2004; Bárcenas and Rosell, 2005). The effects of hydrocolloids on dough and bread properties depend on many factors including different molecular structure, particle size and amount of hydrocolloids, bread recipe, dough and bread preparation methods as well as bread types (Majzoobi *et al*., 2007). Hydrocolloids themselves have a low calorific value and are generally effective in small quantities (Onweluzo *et al*., 1999; Kohajdová, 2009; Mikuš *et al*., 2011). The United State Food and Drug Administration regulate gums, classifying these compounds as either food additives or generally recognized as safe (GRAS) substances (Rodge *et al*., 2012).

Although previous studies on composite breads have shown that substitution of wheat flour with other flours give acceptable bread loaf, increasing the substitution level may lead to reduced bread quality due to the lowered gluten content reducing

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the gas retention capacity. In a previous study, we have fortified white bread with fennel seed powder at different levels of 3, 5, 7, 10 and 15% (w/w). On the basis of sensory, antioxidant and storage properties (crumb moisture and firmness) 7% fennel bread was found to be the optimized product. The aim of the present study was to investigate the effects of some of the most common hydrocolloids i.e. carrageenan, carboxymethylcellulose, guar and xanthan gum on the quality of 7% fennel seed fortified bread. The objectives of the study aims at i) evaluating the effects of the hydrocolloids on bread loaf weight, volume and crumb grain characteristics, ii) examining the staling properties (crumb moisture and firmness) of the bread samples and applying Avrami's non-linear regression equation in studying the bread crumb firming kinetics and iii) understanding the effect of hydrocolloids on rheological properties of bread dough.

Materials and Methods

Materials

Commercial bread-making wheat flour (moisture 13.2±0.45%, ash 0.5±0.25%, dry gluten 10.62±0.98%, protein 11.15±0.62%, fat 1.85±0.12% and carbohydrate 61.68%), sugar, shortening (refined oil) and salt were purchased from the local stores of Jadavpur, Kolkata, India. Compressed Baker's yeast (Saf Yeast Company Pvt. Ltd., Mumbai, India) was used in the fermentation of bread. Glycerol monostearate (Loba Chemie Pvt.Ltd., Mumbai, India) was used in the bread formulation. Packaged fennel seeds were bought from the local grocery shop of Jadavpur, Kolkata. Carrageenan and carboxylmethylcellulose were purchased from Merck Specialities Pvt. Ltd., Mumbai, India and guar gum, xanthan gum, from Himedia Laboratories Pvt. Ltd. (Mumbai, India).

Preparation of fennel seed powder

Fennel seeds were heated to 41±2°C for 1 hr in a hot air oven and then ground to powder in a commercial kitchen grinder (Prestige Stylo Mixer Grinder, Prestige, India). The powder obtained was then sifted to obtain the fennel powder having particle size less than 150 µm (BS 100). The fennel seed powder obtained had a moisture content of 8.81±0.16% and ash content of 66.15±0.05% (AACC, 2000).

Preparation of bread

The bread recipe consisted of compressed yeast 2.5%, sugar 5.0%, salt 2.0%, refined oil 5.0%, glycerol monostearate 1.5% and water 60.0%. Yeast was dissolved in warm water (10 ml at 37°C) and kept for 15 min for activation of the cells. 1 g (approx.) each of flour and sugar were used as feed for yeast. Mixing is an important step for achieving homogenous and soft dough. Here, mixing was carried out manually according to the straight dough method. The dry ingredients, refined oil and the activated yeast were taken in a bowl; requisite amount of water was added and then kneaded for approximately 10 min until the dough was elastic and of required consistency. The dough was then rounded and kept in a bowl for the first proofing at room temperature for about 40 min. A wet cloth was covered over the bowl to maintain a relative humidity of 80-90%. After the first proofing, the dough was punched and worked up lightly so that the excess CO_2 gas could escape out and the gas cells were redistributed in size and space. The dough was then shaped to fit lightly in greased bread molds, and kept for final proofing for about 1 hr at 40±1°C. Finally, after second proofing, the breads in molds were baked in rotary oven (CM HS108, Chanmag Bakery Machine Co. Ltd., Taiwan) at 220±2°C for 18-20 min. The prepared bread samples were cooled for about 1 hr at room temperature and subsequently analyzed for its relevant physical and chemical properties.

Fennel-wheat flour breads were prepared by mixing 100 g wheat flour with 7% (w/w) of coriander leaf powder. Hydrocolloids were added each at four different concentrations of 0.25, 0.50, 0.75 and 1.0% (w/w) on 100 g flour basis. All bread formulations studied in this work and their codes are summarized in Table 1.

Bread loaf size

The loaves were weighed immediately after removal from the baking oven. The loaf volumes of the bread samples were measured by the seed displacement method in ml (Sahin and Summu, 2006) taking a known volume of 700 ml. Specific loaf volumes were calculated by dividing the loaf volume by the loaf weight, and expressed in ml/g.

Crumb moisture

Bread crumb moisture content was determined by taking about 2±1 g of the bread crumb in small aluminium containers and drying for 2 hr at 130±2°C in a hot air oven (Reliance Enterprise, Kolkata, India) (AACC, 2000). After drying, the samples were cooled in desiccators. Moisture content was determined as follows:

$$\%\ \text{moisture content} = \frac{\text{initial wt. of the sample} - \text{final wt. of the sample}}{\text{initial wt. of the sample}} * 100 \quad (1)$$

Crumb firmness

Firmness of the bread samples were measured with Instron Universal Testing Machine, Table Model 4301 (Instron Ltd., High Wycombe, Bucks, UK) in the compression mode fitted with a 100 N load cell. The bread samples were sliced and the middle slices having a height of 25 mm, when placed horizontally under a flat plate probe were taken for measurement. A two-bite crumb compression test was performed by compressing axially each sample with a 40 mm diameter flat plate probe attached to the moving crosshead. The testing conditions were: compression ratio of 50% deformation from the initial height of the sample; 20 mm/min crosshead speed and 20 mm/min chart speed. The force-distance curve obtained was used to derive the firmness of the crumb (Bourne, 1978). The bread loaves after cooling were stored in the refrigerator (approx. 4±2ºC) in metallised food bags (Zipfoil®) for 1, 3, 5, 7 and 14 days and crumb moisture and firmness measured at respective days.

Crumb firming kinetics

The bread firmness values measured at 0, 1, 3, 5, 7 and 14 days of storage were fitted into the Avrami's non-linear regression equation (Armero and Collar, 1998; Angioloni and Collar, 2009):

$$\theta = \frac{T_\infty - T_t}{T_\infty - T_0} = e^{-k*t^n} \qquad (2)$$

Where, θ = fraction of starch recrystallisation still to occur, T_0 = crumb firmness of fresh bread, T_∞ = final crumb firmness, T_t = crumb firmness in't' time, k = rate constant and n = Avrami exponent.

Crumb grain analysis

Crumb grain characteristics of the bread loaves were assessed using a digital image analysis system. The bread loaves were sliced transversely. They were then scanned in colour using a flatbed scanner with a resolution of 300 dpi. The scanned images were then analyzed using Image J software (*http: /rsb.info.nih.gov/ij*) (Ozkoc *et al*., 2009; Turabi *et al*., 2010). The centre of each slice was cropped in a square of 300X300 mm^2 and converted to grey scale (8-bit). For simplicity a 1:1 ratio was maintained while converting pixel into mm. After adjusting the threshold, total no. of cells, total cell area, average cell area, small cell to large cell ratio were determined using the software.

Dough rheology

The dough samples prepared for the dynamic rheological tests consist of the same formulation as that of the bread samples, without yeast. Dynamic oscillatory tests were performed in a controlled stress rheometer, (Physica MCR 51 Anton Paar, Germany). Parallel plates of 49.986 mm and 2 mm gap were used and the measurements monitored with RheoPlus software package (version 2.65). A temperature of 25ºC was kept during the analyses with a water circulator device (Neslab RTE 7, Refrigerated Bath, Thermo Electron Corporation, USA). All samples were allowed to rest for 5 min before measurements to allow dough relaxation. Frequency-sweep tests of the dough samples were performed at a constant strain of 1% and angular frequency ranging between 0.1 and 200 ω. Dynamic moduli G', G'' and tan δ (G''/G') were obtained as a function of frequency. G' is the dynamic elastic or storage modulus, related to the material response as a solid, while G'' is the viscous dynamic or loss modulus, related to the material response as a fluid. tan δ is related with the overall visco-elastic response: low values of this parameter indicate a more elastic nature.

Statistical analysis

All the studies were replicated three times and the means reported. All the experimental data were analyzed statistically for analysis of variance (ANOVA) with Microsoft Excel 2007. Means were compared by Fisher's Least Significant Difference Test at a significance level of $p \leq 0.05$.

Results and Discussion

Bread loaf size

The loaf weight, loaf volume and specific volume of all the bread samples have been elucidated in Table 1. The loaf weight and loaf volume increased significantly in the case of FEN. Further addition of hydrocolloid had no substantial effect on the loaf weight of the final breads. However, the loaf volume seemed to vary significantly depending on the hydrocolloid used and the level of substitution. This variation in the loaf volume has an effect on the specific volume of the bread samples. The specific volume was lowest for CON (2.64 ml/g) while it increased for FEN (2.83 ml/g) owing to an increased loaf weight and volume. The specific volume was found to be higher either at 0.25% or 0.5% hydrocolloid substitution corresponding to the highest loaf volume for that particular hydrocolloid. The specific volume was observed to be highest for CA1' (3.17 ml/g) and lowest for XG4'. Loaf volume had in general a decreasing trend with increasing levels of hydrocolloids as is evident from Table 1. This may be attributed to the fact that at lower concentrations, hydrocolloids are more effective (Kohajdová *et al*., 2009), in their water retention capacity and create a uniform starch-gluten matrix. This matrix in turn inhibits the gases in the dough to

Table 1. Effect of different hydrocolloids in different proportions on fennel breads

Hydrocolloids	Level of hydrocolloids (g/100g)*	Amt. of fennel seed powder (g/100g)*	Sample code	Loaf weight (g)	Loaf volume (ml)	Total cells	Total cell area (mm^2)	Total cell to total area (%)	Ratio of cell ≤ 2mm² to cells ≤ 10 mm² (%)
--	--	--	**CON**	150.77 ± 0.65^{a}	451.11 ± 0.78^{e}	880 ± 13.0^{b}	30101 ± 884.5^{k}	33 ± 0.98^{m}	72 ± 0.004^{p}
--	--	7	**FEN**	152.90 ± 0.61^{b}	433.08 ± 0.26^{f}	890 ± 17.5^{b}	33909 ± 512.0^{l}	38 ± 0.57^{m}	71 ± 0.032^{q}
Carrageenan	0.25	7	**CA1'**	152.62 ± 0.58^{c}	484.49 ± 0.88^{g}	1017 ± 23.07^{c}	30604 ± 3179.03^{k}	34 ± 3.56^{m}	71 ± 0.006^{pq}
Carrageenan	0.5	7	**CA2'**	152.10 ± 0.29^{d}	473.01 ± 0.82^{h}	1207 ± 39.28^{d}	28806 ± 2854.42^{k}	32 ± 3.14^{m}	70 ± 0.019^{r}
Carrageenan	0.75	7	**CA3'**	152.27 ± 0.77^{e}	461.6 ± 0.89^{i}	984 ± 30.83^{cd}	27948 ± 599.48^{m}	31 ± 0.67^{m}	69 ± 0.021^{s}
Carrageenan	1	7	**CA4'**	156.91 ± 0.19^{f}	420.9 ± 0.01^{j}	1021 ± 20.0^{bc}	29706 ± 1245.0^{k}	33 ± 1.38^{m}	70 ± 0.01^{t}
Carboxylmethyl-cellulose	0.25	7	**CMC1'**	153.18 ± 0.10^{g}	431.47 ± 0.01^{ef}	1129 ± 31.09^{a}	30844 ± 31.09^{k}	34 ± 2.0^{m}	71 ± 0.03^{st}
Carboxylmethyl-cellulose	0.5	7	**CMC2'**	154.36 ± 0.57^{h}	456.64 ± 0.87^{gh}	1271 ± 41.88^{e}	29066 ± 41.88^{k}	32 ± 0.42^{m}	70 ± 0.006^{rs}
Carboxylmethyl-cellulose	0.75	7	**CMC3'**	155.83 ± 0.31^{i}	451.80 ± 0.18^{e}	1163 ± 11.5^{a}	29424 ± 245.5^{k}	33 ± 0.27^{m}	70 ± 0.003^{u}
Carboxylmethyl-cellulose	1	7	**CMC4'**	155.96 ± 0.35^{j}	450.95 ± 0.71^{e}	1046 ± 45.4^{ab}	32884 ± 45.4^{n}	37 ± 3.70^{n}	70 ± 0.019^{v}
Guar gum	0.25	7	**GG1'**	152.32 ± 0.58^{k}	452.0 ± 1.76^{e}	1068 ± 43.55^{f}	29697 ± 43.55^{k}	33 ± 0.55^{m}	73 ± 0.009^{w}
Guar gum	0.5	7	**GG2'**	151.92 ± 1.55^{l}	445.3 ± 0.5^{ij}	1154 ± 25.32^{g}	28734 ± 25.32^{k}	32 ± 0.86^{m}	72 ± 0.007^{x}
Guar gum	0.75	7	**GG3'**	155.86 ± 0.71^{m}	428.95 ± 0.45^{o}	1205 ± 14.74^{h}	29009 ± 14.74^{k}	32 ± 0.21^{m}	70 ± 0.002^{y}
Guar gum	1	7	**GG4'**	155.88 ± 0.58^{n}	395.45 ± 0.44^{op}	1030 ± 45.17^{i}	31455 ± 45.17^{k}	35 ± 0.47^{m}	66 ± 0.006^{xy}
Xanthan gum	0.25	7	**XG1'**	152.94 ± 0.2^{o}	434.67 ± 0.76^{m}	1096 ± 9.02^{ae}	33840 ± 9.02^{o}	33 ± 0.59^{o}	69 ± 0.012^{uv}
Xanthan gum	0.5	7	**XG2'**	152.86 ± 0.3^{p}	467.58 ± 1.76^{n}	1175 ± 12.9^{bd}	30344 ± 12.9^{k}	38 ± 0.72^{m}	69 ± 0.012^{rt}
Xanthan gum	0.75	7	**XG3'**	157.81 ± 0.27^{q}	450.73 ± 0.51^{e}	1182 ± 0.58^{de}	29553 ± 0.58^{k}	33 ± 0.06^{m}	72 ± 0.008^{yz}
Xanthan gum	1	7	**XG4'**	155.87 ± 0.41^{r}	396.45 ± 1.08^{kl}	950 ± 42.1^{gh}	26790 ± 42.1^{p}	30 ± 2.26^{p}	69 ± 0.007^{tu}

Data represents means of three samples (n = 3) ± s.d.
Means with different superscripts within the same column are significantly different ($p < 0.05$)

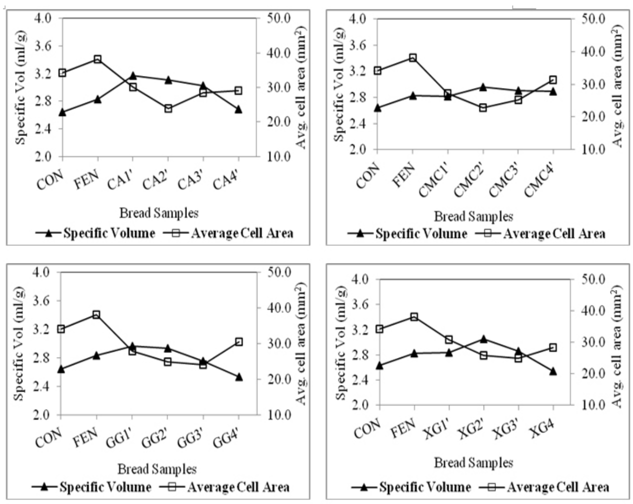

Figure 1. Relationship between specific loaf volume and average cell area of the fennel bread samples

escape while baking. At higher levels of hydrocolloid substitution there may be a breakdown of the starch-gluten matrix owing to an excess amount of water which fails in retaining the gases from the dough.

Crumb grain characteristics

The results from the image analysis of all bread samples have been enumerated in Table 1. The crumb grain characteristics of the samples studied were the total number of cells in a defined crumb area, the total cell area, average cell size, the total cell area to total area ratio and the small cell (≤ 2 mm²) to large cell (≤ 10 mm²) ratio.

As observed from the data, there is no significant increase in the total number of cells between CON and FEN. However, there was a marked increase in the total cell size in the case of FEN which manifests to a much larger average cell size (38.1 mm²) in FEN compared to 34.2 mm² in case of CON. This corresponds to a much higher total cell area to total area ratio in FEN (37.7%) to 33% in CON. Further analysis into the distribution of individual cell sizes reveals that approximately 70 – 72% of the cells were of small size (≤ 2 mm²) suggesting a higher number of large cells (> 2 mm²) in FEN than CON.

On further addition of hydrocolloids to the 7.0% fennel bread, we see a consistent increase in the number of cells in the predefined sample area. However, the total cell area in almost all the breads with hydrocolloids was seen to be more or less unchanged from CON (30101 mm²). The highest total cell area was found in FEN (33909 mm²) and the lowest for XG4' (26790 mm²). The above data can logically explain the consistently lower average cell size in hydrocolloid substituted breads than those in either CON or FEN. The lowest average cell size was seen for 0.5% CA (23.9 mm²).

Analysis into the distribution of cell size for the hydrocolloid substituted breads shows that in almost all the bread samples around 70% of the total cells were small cells. The ratio was been found out to be the highest for GG1' (73.1%) and the lowest for GG4' (66.4%). The above ratio has been found out by comparing the number of small cells (areas ≤ 2 mm²) to the total number cells with area ≤ 10 mm². Any cell with area above 10 mm² has been considered to be an outlier. The cumulative effect of the above data is manifested in a considerably larger number of small cells when hydrocolloid is applied in the bread making process in comparison to either that control or fennel bread. This effect of hydrocolloid substitution may be directly attributed to the fundamental properties of hydrocolloids as a texture improver in bread dough

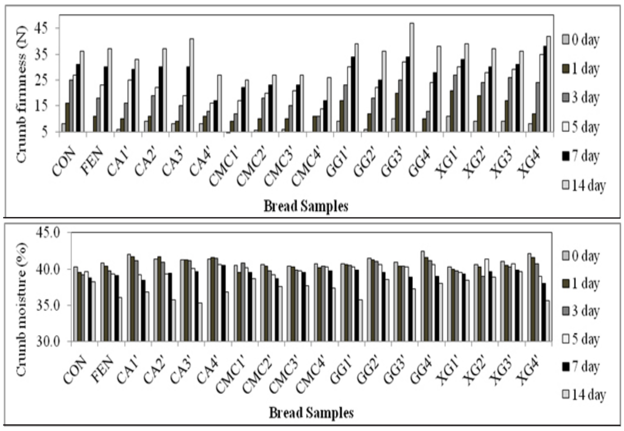

Figure 2. Crumb firmness and moisture of the bread samples with storage days

(Kohajdová *et al*., 2009; Rodge *et al*., 2012) where in, they stimulate the porosity of the final bread product by creating a uniform starch-gluten matrix. Some large cells were also noticed on the sliced area, a well known characteristic of flours with disturbed viscoelastic properties (Scanlon *et al*., 2000; Zghal *et al*., 2001).

Relationship between loaf specific volume and average cell area

The interpretation of the effects of hydrocolloids on the crumb texture is further reinforced from the inverse relationship we found between the specific volumes of the bread samples and the corresponding average cell size (Figure 1). This relationship was found to hold true for almost all the bread samples and may be reasoned as follows:

i. Addition of hydrocolloids prevents smaller cells from coalescing together and thus inhibits the formation of bigger cells

ii. The larger number of small cells help creates a uniform matrix acts as a mesh preventing CO_2 gas to escape during the baking process

iii. This effectively increases the loaf volume and hence the specific volume in case of hydrocolloid substituted breads.

Crumb moisture and crumb firmness

The objectives of this study was to investigate the changes in bread crumb firmness and moisture that occur with increasing storage days. Figure 2 depicts the crumb firmness and moisture values for all the samples on specific days during storage, namely, 0, 1, 3, 5, 7 and 14 days. Crumb firmness values for all the bread samples increased with storage days while crumb moisture was observed to decrease during the same time period. As such, the usual inverse relationship between crumb moisture and firmness was found to hold for all bread samples

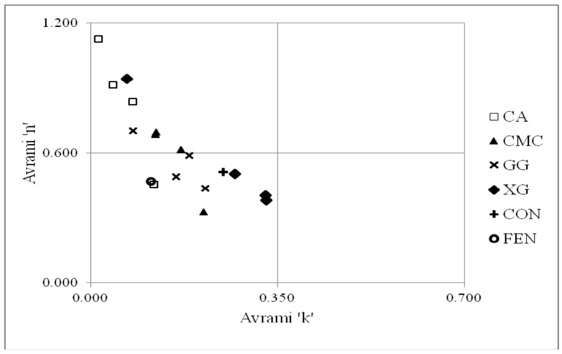

Figure 3. Relationship between avrami ‘n’ and ‘k’ in scattered plot

over a period of 14 days (Rogers *et al*., 1988; He and Hoseney, 1990).

Hydrocolloids in general with the exception of CMC had a positive effect in increasing the crumb firmness. The highest crumb firmness was observed in bread GG3’. In general, both CA and XG showed consistently higher firmness values on days 7 and 14 for all levels of substitution. CMC had the least impact in changing the crumb firmness for all levels of substitutions for all storage days. The decrease in crumb moisture was less prominent during storage. Bread samples with hydrocolloids incorporated had more crumb moisture content in general (Sharadanand and Khan, 2003; Kohajdová and Karovičová, 2009). This may have affected the crumb firmness values by the formation of cross-links between partially solubilised starch and gluten proteins (Martin *et al*., 1989). Decrease in crumb moisture is known to accelerate the formation of cross links between starch and protein and, thus, the bread may firm faster (He and Hoseney, 1990).

Crumb firming kinetics

Crumb firmness of all bread samples including control and fennel breads were modeled using the Avrami equation and kinetic parameters, ‘n’ and ‘k’, were calculated by fitting the observed data. Substitution of fennel into white bread decreased the ‘k’ value by more than 50% suggesting a slower rate of firmness kinetics. Substitution of hydrocolloids on fennel optimized bread seemed to have different effects depending on the type of hydrocolloid used. CA, CMC and GG showed ‘k’ values consistently lower than CON at all levels of concentrations. CA in particular showed extremely low ‘k’ values while for CMC and GG the ‘k’ values at 1.0% substitution was found to be higher than other levels. XG, on the other hand had higher values till 0.75% and extremely low ‘k’ value at 1.0%. However, to understand the effects of ‘k’ values on the firming kinetics, we also need to consider the ‘n’ values. Higher ‘k’ values are

Table 2. Rheological parameters of the bread dough samples

Sample codes	Frequency sweep test parameters		
	(Pa)	tan(δ)	(Pa.s)
CON	8230.0 ± 850^{a}	0.48 ± 0.01^{m}	1340.0 ± 140
FEN	10415 ± 2485^{a}	0.52 ± 0.01^{n}	1695 ± 405
CA1'	14600 ± 500^{b}	0.58 ± 0.03^{o}	2365 ± 75
CA2'	12533 ± 2831^{c}	0.58 ± 0.02^{p}	2037 ± 462
CA3'	16333 ± 2706^{d}	0.56 ± 0.01^{mn}	2653 ± 444
CA4'	19833 ± 961^{e}	0.54 ± 0.03^{op}	3223 ± 158
CMC1'	9903 ± 6441^{a}	0.55 ± 0.02^{q}	6600 ± 7622
CMC2'	15300 ± 954^{ab}	0.59 ± 0.04^{pq}	2487 ± 150
CMC3'	13500 ± 2621^{bc}	0.59 ± 0.01^{r}	2197 ± 427
CMC4'	20467 ± 2442^{ad}	0.58 ± 0.02^{s}	3323 ± 400
GG1'	16833 ± 850^{ef}	0.54 ± 0.01^{t}	2737 ± 140
GG2'	23000 ± 5173^{gh}	0.57 ± 0.02^{rs}	3737 ± 487
GG3'	19800 ± 173^{bd}	0.53 ± 0.03^{st}	3220 ± 26
GG4'	22933 ± 404^{ae}	0.53 ± 0.02^{rt}	3720 ± 69
XG1'	13767 ± 153^{ad}	0.53 ± 0.02^{u}	2247 ± 25
XG2'	19400 ± 1706^{g}	0.51 ± 0.02^{v}	3153 ± 273
XG3'	23150 ± 1750^{h}	0.48 ± 0.01^{m}	3760 ± 280
XG4'	19300 ± 737^{cd}	0.43 ± 0.03^{uv}	3140 ± 104

Data represents means of three samples (n = 3) ± s.d.
Means with different superscripts within the same column are significantly different ($p < 0.05$)

usually associated with lower 'n' values and vice versa (Armero and Collar, 1998). The 'n' and 'k' values were plotted in a scattered plot to examine the correlation between them (Figure 3).

Figure 3 shows that 'k' values for all the samples are on the lower half and no samples were found were both 'n' and 'k' had higher values. It is evident from these findings that adding hydrocolloid to fennel has a far more effect on restricting the 'k' values. Most of the bread samples containing GG or XG had low 'n' and 'k' values suggesting slower crumb firming kinetics. The noticeable observation in this case was in CA which had higher 'n' values and lower 'k' values which collectively may increase the crumb firming kinetics.

Dough rheology

The shear stress-shear rate profile from the rheological data confirmed the pseudo-plastic nature of the bread samples. Amplitude sweep tests of the bread samples suggested a profile where both G' and G'' decreased with increasing stress. The crossover points (G' = G'') in the profile gave an idea of the flow stress in the samples. The crossover points were found to increase substantially on application of hydrocolloids implying an increased rigidity while the measures for CON and FEN were comparable and much lower. Use of 1.0% strain was proposed from the amplitude sweep test for all the samples for performing the frequency sweep tests.

From the frequency sweep tests, tan δ (damping factor), complex modulus (G^*) and complex viscosity (η^*) were studied (Table 2). Tan δ values were found to be in the range of 0.43 – 0.59 suggesting that for majority of the samples G' values were around twice as large as G'' (Table 2). As such it may be said that the elastic component (G') dominated the complex modulus (G^*) values. The G^* value in FEN was found to be considerably higher than CON. Application of hydrocolloids revealed variation in the effects on the rheological parameters depending on the type and level of substitution of each of the hydrocolloids. In general, G^* and η^* values increased on hydrocolloid addition. The highest G^* values were seen for GG2', GG4' and XG3'. The η^* profile derived from the frequency sweep test showed a monotonically decreasing function of angular frequency. The F-ratio statistics of the ANOVA of the η^* data was found to be insignificant, implying that the complex viscosity of the samples were not different statistically between themselves.

Conclusion

Addition of hydrocolloids was found to improve the crumb quality significantly most notably due to an increased loaf volume and a uniform texture owing to an increased porosity. The effects of hydrocolloids as a texture improver was further reinforced by an inverse relationship between the specific volume and average cell size of the final bread products. The role of hydrocolloids in moisture retention was slowest in case of XG. This corroborates with the findings from Avrami's crumb firming kinetics which showed that XG had better effect in lowering crumb firming rate. CA on the other hand showed faster crumb firming kinetics. Application of hydrocolloids also increased the complex modulus, most notably in GG and XG, suggesting an increase in the viscous quality of the breads.

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