Rheological and sensory behaviour of rice flour dough: effect of selected additives in relation to dough flattening

Yash Dixit · Suvendu Bhattacharya

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Abstract The handling of rice flour doughs in terms of sheeting, flattening and rolling is difficult due to the absence of gluten forming proteins; scope exists to improve these characteristics by incorporating appropriate additives during the preparation of rice doughs. Different levels of additives such as whey protein concentrate (WPC) (0–10 %), xanthan gum (0–5 %), sucrose (0–20 %) and salt (0–2 %) have been incorporated, and the rheological (small-deformation oscillation) as well as sensory characteristics have been determined, in addition to microstructural observations and finding inter-relationships. The second order polynomial can adequately explain the rheological parameters like storage modulus, loss modulus and complex viscosity ($R=0.863$ – 0.889 , $p\leq 0.01$) while it is poor for phase angle ($R=0.659$, $p\leq 0.01$). Among these additives, xanthan gum imparts the strongest effect (significant at $p\leq 0.01$) followed by whey protein concentrate. The effects of these additives are predominantly linear though quadratic effects are also significant in several cases. A cohesive microstructure with improved binding occurs with a high level (7.5 %) of WPC. It is concluded that a judicious selection of additives in appropriate levels can develop rice doughs that possess the desirable handling properties leading to preparation of products.

Keywords Rice dough · Additives · Oscillation · Microstructure · Sensory assessment · Interrelation

Introduction

Understanding of the rheological behaviour of doughs is necessary for their handling/processing and subsequent product development. This is particularly important for compression/flattening/sheeting/rolling purposes in order to have an efficient control of the quality of the final product. The deformation behaviour of doughs is thus recognised to be the central focus for the successful manufacturing of wheat-based bakery products to ensure consistent production. However, the investigations on the viscoelastic characterisation of rice flour doughs are rather limited with particular reference to inter-relating dough behaviour and their handling characteristics.

Rice is free from gluten and is the least allergenic; however, the absence of gluten in rice makes the dough to be significantly less stretchable and poor in cohesiveness compared to wheat doughs. Thus, the rice flour doughs lack good handling properties which offer serious problems during their handling and the preparation of rice dough based products. Hence, it is desirable to develop machine compatible rice-based products or partially substitute rice flour for wheat flour in different food products. The milling of rice results in the production of broken grains, which are usually used for making traditional Oriental foods (Bhattacharya and Bhat 1997), and for brewing. If it is possible to make consumer acceptable rice products like bread from these broken grains, it will not only use effectively the broken grains to convert it to a value added product but also will be a better alternative for gluten allergic patients (Nishita and Bean 1979; Ylimaki et al. 1988; Mi et al. 1997). These studies indicate the usefulness of an additional binder for developing rice flour dough based bread. The amylose content of milled rice is found to be closely (but negatively) associated with the consistency, and positively with springiness of rice bread (Sivaramakrishnan et al. 2004); these investigators have compared rheological

Y. Dixit · S. Bhattacharya (✉)
Food Engineering Department, CSIR-Central Food Technological
Research Institute, Mysore 570020, India
e-mail: suvendu@cftri.res.in

S. Bhattacharya
e-mail: suvendu1111@yahoo.co.in

properties of rice and wheat doughs for making rice bread. Lazaridou et al. (2007) have studied the effect of hydrocolloids on doughs made from rice flour, corn starch and sodium caseinate. The effect of carboxymethylcellulose (CMC)-hydroxypropylmethylcellulose (HPMC)-water combinations has been reported to replace gluten in the rice flour yeast breads (Ylimaki et al. 1988). Rheological properties of rice pasta dough have been studied by creep-recovery tests for various formulations containing guar gum, casein and egg white mixtures (Sozer et al. 2008). The creep-recovery data show that incorporation of gelatinised fraction increases the elasticity of the samples.

There exists a scope to incorporate protein and/or hydrocolloid based additives to modify the rheological properties of rice doughs in relation to product development (Saha and Bhattacharya 2010). Hydrocolloids are able to control the rheological characteristics of dough and even the quality attributes of the finished products such as the textural attributes of the bakery products. They can also improve dough handling properties and extend the shelf-life of bread (Rosell et al. 2001a). A hydrocolloid like xanthan gum is suitable in such a situation. Xanthan gum has been added to composite cassava-wheat dough to improve the viscoelastic properties (Shittu et al. 2009); the stability of wheat dough is reported to improve with the use of xanthan gum (Rosell et al. 2001a, b) and elasticity of dough in gluten-free formulations (Crockett et al. 2011). The extent of water absorption increases markedly when hydrocolloids are used alone or in combination (Sahraian et al. 2013). The use of whey protein concentrate increases protein content, and improves flavour, texture and nutritional status of the product (Pereira et al. 2007). Whey protein concentrate (WPC), even at a low level of 5 %, has been reported to significantly change the elasticity and consistency of wheat flour dough (Conforti and Lupano 2004). The addition of common salt and sugar induces the taste; in addition, salt causes rheological modification of wheat dough (Beck et al. 2011). Salt also induces flavour in the bakery products and controls the process of dough fermentation. The use of sugar adds sweetness, affects texture, colour and flavour of the baked products (Matz and Matz 1978). However, the type and level of protein and/or hydrocolloid based additives are important to decide the rheological status of dough and the attributes of the finished product which are worth for investigation. Hence, the objectives of the present study are to (a) determine the rheological and sensory properties of rice flour doughs with selected additives like whey protein concentrate, xanthan gum, sugar and salt, and (b) inter-relate rheological and sensory attributes of doughs.

Materials and methods

Materials

Rice flour (variety *Bacillus thuringiensis*, popularly called BT and is a super fine grade rice variety) was procured from a local supermarket. The proximate composition of flour, as determined on triplicate samples by employing AACC (2000) methods, was moisture: 9.1 %, protein (reported as total nitrogen content multiplied by a factor of 5.95): 5.5 %, fat: 0.4 %, ash: 0.4 % and carbohydrate (by difference): 84.6 %. Xanthan gum was purchased from Loba Chemie, Mumbai, India. Whey protein concentrate (WPC) has a proximate composition of moisture 6.9 %, protein 72.3 % (Nx6.25), fat 2.5 % and total ash 1.2 %; it was procured from Mahaan Foods, Coimbatore, Tamil Nadu, India. Common salt (RFCL Limited, analytical reagent, New Delhi, India) and cane sugar (sucrose) (manufactured by Simbhaoli Sugars, Ghaziabad, Uttar Pradesh, India) were also purchased from a local supermarket at Mysore, India. The particle size, as determined by examining 250 rice flour particles in a scanning electron microscope (model # 435 VP, Leo Electronic System, Cambridge, UK), was between 7 and 73 μm (discussed later), and their shape varied from spheroids to ellipsoids.

Dough preparation

Water was added to rice flour to attain the desired moisture content (50 %, wet basis) having additives like WPC (0–10 %), xanthan (0–5 %), sugar (0–20 %) and salt (0–2 %) as per the experimental design (discussed later). The range of the additives was decided based on initial trials. The dough formulations were prepared by replacing part of the flour with different combinations of additives. These ingredients were mixed for 15 min in a Hobart mixer at a low speed to obtain homogeneous doughs. Dough samples without additives were also made maintaining the same moisture content. The dough samples, prior to rheological testing, were checked again for their moisture contents. All experiments were repeated twice.

Oscillation testing

All measurements were performed at 25 °C using a controlled-stress rheometer (Model # RS6000, Thermo Scientific, Karlsruhe, Germany) (Bhattacharya and Jena 2007). Dough samples were placed between the serrated plate and the base (35 mm in diameter), and compressed to 1 mm and the excess dough was trimmed off. A thin layer of paraffin oil was placed around the sample to avoid drying. The dough was rested on the same geometry for 10 min prior to further measurement. Dynamic oscillatory testing was conducted with stress sweep test from 0.01 to 1,000 Pa at 1 Hz to identify the linear viscoelastic (LVR) region. Frequency sweep tests were

conducted between 0.01 and 100 Hz in the LVR region of 200 Pa to determine storage modulus (G'), loss modulus (G''), complex viscosity (η^*) and phase angle (δ). The reported values for G' , G'' , η^* and δ were corresponding to a frequency of 1 Hz for comparison of results. All experiments were performed on triplicate samples.

Sensory analysis

The 3-digit coded rice flour doughs, prepared with different additives as shown in Table 1, were subjected to non-oral sensory assessment using fingers and hand. The sensory attributes such as hardness, stickiness and springiness were measured by nine trained panellists using the index finger for

compression of the sample. A 10-point scale was used to report the attributes. The control sample (rice dough without additive) was also assessed in a similar manner. Stickiness was the tendency to adhere to contacting surfaces especially to index finger during repeated gentle compression (Tiwari et al. 2012). Springiness was the degree to which the sample returned to the original shape after partial compression. Hardness was the force offered by the sample during compression. All sensory assessments were repeated twice.

Inter-relationship

Rheological (G' , G'' , η^* and δ) and sensory attributes (hardness, stickiness and springiness) for all the

Table 1 Design of experiment employed

Expt. No.	Variables (coded level)				Variables (actual level)			
	Whey protein concentrate, x_1 (%)	Gum, x_2 (%)	Sucrose, x_3 (%)	Salt, x_4 (%)	Whey protein concentrate, X_1 (%)	Gum, X_2 (%)	Sucrose, X_3 (%)	Salt, X_4 (%)
1	0	0	0	0	5	2.5	10	1
2	−1	1	−1	−1	2.5	3.75	5	0.5
3	−1	−1	−1	1	2.5	1.25	5	1.5
4	−1	−1	1	1	2.5	1.25	15	1.5
5	1	−1	−1	−1	7.5	1.25	5	0.5
6	−2	0	0	0	0	2.5	10	1
7	−1	1	1	1	2.5	3.75	15	1.5
8	0	0	−2	0	5	2.5	0	1
9	0	0	0	0	5	2.5	10	1
10	0	−2	0	0	5	0	10	1
11	0	0	0	0	5	2.5	10	1
12	0	0	0	2	5	2.5	10	2
13	−1	1	−1	1	2.5	3.75	5	1.5
14	0	0	0	0	5	2.5	10	1
15	1	−1	1	1	7.5	1.25	15	1.5
16	0	0	0	−2	5	2.5	10	0
17	1	1	−1	−1	7.5	3.75	5	0.5
18	0	2	0	0	5	5	10	1
19	0	0	0	0	5	2.5	10	1
20	2	0	0	0	10	2.5	10	1
21	0	0	0	0	5	2.5	10	1
22	−1	1	1	−1	2.5	3.75	15	0.5
23	1	1	1	−1	7.5	3.75	15	0.5
24	−1	−1	−1	−1	2.5	1.25	5	0.5
25	1	−1	−1	1	7.5	1.25	5	1.5
26	1	1	1	1	7.5	3.75	15	1.5
27	0	0	0	0	5	2.5	10	1
28	−1	−1	1	−1	2.5	1.25	15	0.5
29	1	1	−1	1	7.5	3.75	5	1.5
30	1	−1	1	−1	7.5	1.25	15	0.5
31	0	0	2	0	5	2.5	20	1

experiments were inter-related by applying the methodology of principal component analysis (PCA) (Lawless and Heymann 1998) using the statistical software Statistica '99 (StatSoft, Tulsa, OH, USA).

Microstructure

Rice flour dough samples (with and without additives) were dried with increasing concentration of ethyl alcohol. The dried dough pieces and rice flour were placed on the sample holder using double-sided electricity-conducting adhesive tapes, and were exposed to gold sputtering using a sputter coater. Samples were subjected to scanning electron microscopic examination using a scanning electron microscope (model # 435 VP, Leo Electronic System, Cambridge, UK) at an accelerating voltage of 15 kV. Representative photomicrographs were obtained and presented.

Design of experiments and statistics

Duncan's multiple range test (DMRT) was applied to determine the statistical differences among the experimental values, and the level of significance used to test them was at $p \leq 0.05$ (Little and Hills 1978). A central composite rotatable design (CCRD) of experiments was used in the present study. The independent variables (additives for dough) were the concentrations of WPC (X_1), gum (xanthan) (X_2), sugar (sucrose) (X_3) and salt (X_4) following the response surface methodology (RSM) (Khuri and Cornell 1989). The four response functions were the storage modulus, loss modulus, complex viscosity and phase angle. The independent variables were coded to 5 levels such as -2 , -1 , 0 , 1 and 2 . The experimental design in the actual (X) and coded (x) levels of variables is shown in Table 1. The response functions (Y_{ijk}) were approximated by a second degree polynomial (Eq. 1) with linear, quadratic and interaction effects.

$$Y_{ijk} = b_0 + \sum_{i=1}^n b_i x_i + \sum_{i=1}^n \sum_{j=1}^n b_{ij} x_i x_j + \epsilon_{ijk} \quad (1)$$

$i \leq j$

The number of variables was denoted by n and j , while k and i were the integers. The coefficients of the polynomials were b_0 (constant term), b_i (linear effect) and b_{ij} (quadratic effect), and ϵ_{ijk} was the random error. If $i < j$, b_{ij} represented the interaction effects of the variables x_i and x_j . The response surface graphs were generated from the regression equations in actual level of variables. The detailed analysis of variance (ANOVA) was conducted (in coded level of variables) to know the effects of individual variables as linear, quadratic and interaction effects; the significance of these effects was judged by t -values at $p \leq 0.10$, 0.05 and 0.01 .

Results

Oscillation testing

The effect of four independent variables (WPC, gum, sugar and salt contents) on the four rheological response functions (storage modulus, loss modulus, complex viscosity and phase angle) is shown in Table 2 while Table 3 shows the condensed analysis of variance (ANOVA) in coded level of variables.

The sample frequency sweep graph (Fig. 1) shows that an increase in frequency increases G' and G'' , but decreases η^* drastically. For all the samples, $G' \gg G''$ indicating a prominent solid like behaviour (viscoelastic rather than elastoviscous) of these rice dough samples. Table 2 also indicates that the rice dough without any additive possesses higher G' values (in all cases except experiment # 8 and 17) compared to doughs with additives. It means that the G' values for rice doughs decrease in the presence of additives which possibly help them during flattening/rolling/sheeting operations.

The second order polynomial (Eq. 1) can adequately explain the rheological parameters like G' , G'' and η^* ($R=0.863$ – 0.889 , $p \leq 0.01$) while it is poor for δ ($R=0.659$, $p \leq 0.01$). The coefficients of polynomials relating to storage modulus (Table 3) shows that the linear effect of the variables is prominent. Among all the four variables, the linear effect of gum has the strongest positive effect followed by sugar; the latter has a negative linear effect followed by salt having a negative linear effect (Fig. 2) ($p \leq 0.01$). WPC has the least positive linear effect which is also less significant (at $p \leq 0.10$). The quadratic effect of these variables is usually non-significant except for gum and sugar. Gum alone has a negative quadratic effect (significant at $p \leq 0.01$), while that of sugar is positive and less significant (at $p \leq 0.10$). These phenomena produce a curvilinear effect on G' . The positive effect of gum in addition to negative quadratic effect of the same indicates that at a low level of gum, it increases G' while at a higher value, it decreases G' producing complex behaviour.

The coefficients of polynomials (Table 3) for loss modulus (G'') point towards the dominance of the linear effects of variables. Gum is the most dominant variable showing a positive linear effect while salt shows the least negative linear effect (Fig. 2). Sugar has a negative linear effect followed by the positive linear effect of WPC. The quadratic effects of these variables and that for their interactions are non-significant except for gum alone which has a negative effect (significant at $p \leq 0.05$). This phenomenon produces a curvilinear effect of gum on G'' .

The coefficients of polynomials for complex viscosity (η^*) indicate the higher impact of linear effect of variables. Gum is most dominant with a positive linear effect (Table 3, Fig. 2) followed by the negative linear effect of sugar. Salt also gives a negative linear effect and the least effect is of WPC which is

Table 2 Response functions related to rheological testing of rice doughs

Expt no.	Response functions			
	Storage modulus, G' (Pa)	Loss modulus, G'' (Pa)	Complex viscosity, η^* (mPas)	Phase angle, δ (°)
1	65090±2754	11390±303	10516667±440946	9.93±0.19
2	99787±3938	16273±737	16086667±637364	9.26±0.05
3	64955±700	11905±262	10510000±98995	10.36±0.33
4	40703±2008	7819±358	6611666±345193	10.88±0.20
5	77030±2494	13753±549	12456663±406981	10.12±0.11
6	67513±5545	10480±508	10876000±884753	8.84±0.34
7	73487±5871	12760±803	11873333±942461	9.86±0.16
8	116433±4821	20210±639	18810000±770779	9.85±0.12
9	68373±4388	13807±779	11103333±710587	11.42±0.09
10	9302±6918	3565±1474	1591500±1112419	23.71±5.97
11	91617±2176	16843±560	14826667±346458	10.42±0.33
12	53847±3860	11197±880	8753333±629854	11.74±0.11
13	93037±10695	16093±2391	15026667±1744315	9.79±0.37
14	81367±7433	14337±1468	13146666±1204215	9.99±0.13
15	55517±3519	11730±836	9031000±574905	11.93±0.15
16	100713±2831	18693±497	16300000±450333	10.52±0.12
17	116867±1701	21440±1101	18910000±251595	10.39±0.62
18	90793±2668	16680±599	14696666±417892	10.41±0.48
19	83910±5705	14720±1244	13560000±926984	9.94±0.21
20	82277±12582	15630±3081	13330000±2060291	10.71±0.45
21	74083±8984	12603±2220	11963333±1470283	9.62±0.52
22	77040±4160	14023±835	12466667±675006	10.31±0.09
23	88970±2411	17273±544	14423333±390683	10.99±0.19
24	74777±2309	12553±608	12066668±375544	9.53±0.18
25	79457±3503	15513±551	12886667±562168	11.05±0.15
26	67010±7816	12680±1855	10854333±1276838	10.69±0.30
27	63865±2482	11305±375	10320000±395980	10.04±0.06
28	55607±1963	10817±451	9016000±319611	11.01±0.14
29	102840±2818	18253±515	16626667±457639	10.06±0.09
30	65123±4446	14057±1409	10603667±738431	12.11±0.36
31	57033±4026	11537±817	9261000±653229	11.44±0.05
Rice dough without additive	108220±8191	14160±1260	17373333±13216	7.45±0.14

also least significant (at $p \leq 0.05$). A comparison of the quadratic effect of these variables shows that only gum and sugar have the significant effects, whereas other variables and their interactions have non-significant effects. Gum shows a negative quadratic effect (significant at $p \leq 0.01$) while sucrose shows a less significant positive quadratic effect (at $p \leq 0.05$). These phenomena produce a curvilinear effect on η^* .

The coefficients of polynomials for phase angle show that only gum possesses a significant effect at $p \leq 0.01$. The negative linear effect and the positive quadratic effect indicate that at a low level of gum, it decreases the phase angle (δ) while at a high level it increases the same (graph not presented).

Microstructure

Microstructural examination has been conducted to observe the nature of binding in a rice dough with/without additives. The photomicrograph (Fig. 3a) shows that rice flour particles are apart from each other and are of varying size (7 to 73 μm) and shape (spheroids to ellipsoids). The outer surface of the particle is rough and appears to be damaged possibly due to the grinding process. The photomicrograph (Fig. 3b) of rice flour dough (without any additive) shows the formation of a cohesive network due to interaction of flour particles with water. It shows the binding of particles with adhesive-like

Table 3 Condensed analysis of variance (ANOVA) for parameters of oscillation testing in coded level of variables

Source of variation	Storage modulus, G' (Pa)		Loss modulus, G'' (Pa)		Complex viscosity, η^* (mPas)		Phase angle, δ (°)	
	Coefficient of polynomial	t -value	Coefficient of polynomial	t -value	Coefficient of polynomial	t -value	Coefficient of polynomial	t -value
Constant	75472	20.01***	13572	19.67***	12205238	20.05***	10.194	13.48***
x_1	4290	2.11*	1365	3.66***	710111	2.16**	0.420	1.03 ^{NS}
x_2	15369	7.54***	2370	6.36***	2470653	7.52***	-1.343	-3.29***
x_3	-12670	-6.22***	-1749	-4.69***	-2032833	-6.18***	0.433	1.06 ^{NS}
x_4	-7164	-3.52***	-1185	-3.18***	-1154278	-3.51***	0.139	0.34 ^{NS}
x_1^2	651	0.35 ^{NS}	-15	-0.04 ^{NS}	101659	0.34 ^{NS}	-0.377	-1.01 ^{NS}
x_2^2	-5560	-2.98***	-748	-2.19**	-888070	-2.95***	1.445	3.86***
x_3^2	3611	1.94*	689	2.02 ^{NS}	584784	1.94**	-0.159	-0.43 ^{NS}
x_4^2	1248	0.67 ^{NS}	457	1.34 ^{NS}	207576	0.69 ^{NS}	-0.038	-0.10 ^{NS}
x_1x_2	-547	-0.22 ^{NS}	-91	-0.20 ^{NS}	-88292	-0.22 ^{NS}	-0.032	-0.07 ^{NS}
x_1x_3	-866	-0.35 ^{NS}	-113	-0.25 ^{NS}	-140333	-0.35 ^{NS}	0.061	0.12 ^{NS}
x_1x_4	-509	-0.20 ^{NS}	-204	-0.45 ^{NS}	-86292	-0.21 ^{NS}	-0.041	-0.08 ^{NS}
x_2x_3	-1672	-0.67 ^{NS}	-376	-0.82 ^{NS}	-273417	-0.68 ^{NS}	-0.157	-0.32 ^{NS}
x_2x_4	-899	-0.36 ^{NS}	-313	-0.69 ^{NS}	-150125	-0.37 ^{NS}	-0.125	-0.25 ^{NS}
x_3x_4	-1366	-0.55 ^{NS}	-558	-1.22 ^{NS}	-229333	-0.57 ^{NS}	-0.189	-0.38 ^{NS}
R	0.889***	0.863***	0.888***	0.659***				

Variables: x_1 Whey protein concentrate (%), x_2 Gum (xanthan) (%), x_3 Sucrose (%), and x_4 Salt (%)

*Significant at $P \leq 0.10$; ** Significant at $P \leq 0.05$; ***Significant at $p \leq 0.01$; ^{NS} Non-significant at $p = 0.10$

substances that are possibly formed by leached out materials during mixing of flour with water. Hence, these leached materials, possibly made of soluble starch and/or protein, can offer the base for holding the rice flour particles together in dough samples.

Rice flour doughs with different level of additives are shown in Fig. 3c and d. The effect of binder, particularly WPC, plays an important role on the microstructure. A low

level of WPC (2.5 %) does not offer any significant difference in the microstructure (Fig. 3c) while a higher level of 7.5 % shows a more cohesive structure with improved binding (Fig. 3d). In the latter photomicrograph, the individual particles are visible in a bed of adhesive material, mainly contributed by WPC. However, the effects of salt and sugar are not noticeable in the photomicrographs.

Sensory analysis

The non-oral sensory assessments, in terms of hardness, springiness and stickiness, are shown in Table 4. Raw rice flour dough, in absence of additives, is very hard and exhibits high extent of elasticity or springiness but only a little stickiness.

The experiment # 10 does not yield any dough but it forms a thick batter. This sample does not have any springiness but is extremely sticky. All other samples show varied extent of hardness, springiness and stickiness. The sensory panel has an opinion that a moderate hardness of dough in combination with a moderate extent of springiness and low stickiness are the desirable features considering a dough to be flattened/rolled/sheeted/shaped to make different products. Thus, the samples # 13, 14 and 28 appear suitable. The corresponding levels of WPC, gum, sugar and salt are 2.5–5.0, 1.25–3.75, 5–10 and 0.5–1.5 %, respectively.

Fig. 1 Sample frequency sweep plots showing the changes in storage modulus (G'), loss modulus (G'') and complex viscosity (η^*). Symbols used are G' (●), G'' (▲) and η^* (▼). Solid symbols represent the control rice flour dough and empty symbols are for sample rice dough with 5 % WPC, 5 % xanthan, 10 % sucrose and 1 % salt

Fig. 2 Storage modulus (G'), loss modulus (G'') and complex viscosity (η^*) of rice flour doughs as a function of additives

Inter-relationship

The principal component analysis plot (Fig. 4) among instrumental rheological indices and sensory attributes indicates that PC1 accounts for 52 % of the variation while PC2 accounts for 14 %. Among the instrumental rheological indices, the storage modulus, loss modulus and complex viscosity behave in a similar manner. On the other hand, phase angle performs in an opposite manner to these three instrumental parameters. The sensory attributes like hardness and springiness behave in a similar manner while the effect of stickiness is different compared to these two former attributes. Rice flour dough without any additive (sample #32) possesses a good hardness and springiness due to its presence in the same quadrant. In a similar manner, the sample #10 has a high phase angle meaning its liquid status to acts as an outlier for the rice flour dough samples studied in the present investigation.

Discussion

Effect of gum

Low moisture containing corn flour doughs without gum have been reported to exhibit more pronounced viscoelastic solid behaviour than samples with higher moisture content and/or with gum (Bhattacharya et al. 2003). This is also true for rice flour doughs in the present study. The addition of water-binding compounds like hydrocolloids assists in absorbing excess moisture that is latter released to disrupt the gluten network (Asghar et al. 2007). Shalini and Ananthanarayan Laxmi (2007) have incorporated several hydrocolloids at various levels between 0.25 and 1.0 % of whole wheat flour and have reported that amongst the hydrocolloids studied, guar gum gives the highest extensibility for fresh and stored *chapatti* (Indain unleavened flat bread). The addition of gum

Fig. 3 Photomicrograph of (a) raw rice flour (2000X), and rice flour doughs (b) without any additives, (c) with 2.5 % WPC, 3.75 % xanthan, and (d) 7.5 % WPC, 1.25 % xanthan at magnifications of 10,000×

in dough can induce several changes. It can affect the protein network formation, allow dough plasticity and cohesiveness. Rosalina and Bhattacharya (2001) have mentioned that viscoelastic properties of the composite system may depend on several factors such as (a) the rigidity of the dispersed particles, (b) viscoelasticity of continuous phase, and (c) adhesion between the dispersed and continuous phase. If gum is used, the factor (a) decreases, but (c) increases giving an overall increase in binding because the basic function of gum is adhesion (Bhattacharya et al. 2003).

In gluten-free formulations, xanthan has been reported to increase dough elasticity by increasing G' while decreasing G'' as depicted by a depression of the $\tan \delta$ values (Crockett et al. 2011). In rice dough, this phenomenon has been observed and thus xanthan can increase dough elasticity by increasing G' while decreasing G'' as depicted in the depression of δ values (experiment # 11 and 13).

Effect of WPC

The addition of 5 % WPC (containing 80 % protein) has been reported to produce a reduction in the firmness, elasticity and consistency, and an increase in the cohesiveness of wheat flour dough (Conforti and Lupano 2004). The effect of WPC can be explained by postulating that whey proteins interfere with the normal structure of gluten (Lupano 2000). Significant differences ($p \leq 0.05$) in elasticity have been found between doughs prepared with different amounts of WPC. If the gum content is kept constant, an increase in WPC increases the storage modulus of rice doughs marginally (Fig. 2). It may be

mentioned here that all these ingredients compete for water and thus a composite behaviour is expected.

Substitution of wheat flour with WPC has been reported to decrease farinograph water absorption; an increase in dough stability has been observed up to 10 % level of WPC addition compared to control sample (Indrani et al. 2007). However, there is a decrease in dough stability beyond 10 % level of addition. Incorporation of WPC has been reported to decrease the water absorption capacity from 59.3 to 53.5 % but increases the refined wheat flour dough development time from 2.5 to 8.0 min (Sudha et al. 2010) during the preparation of high-protein vermicelli. It is possible that WPC in a rice dough competes for water during dough preparation, and absorbs water faster than rice flour such that the latter item gets less available water to absorb. This situation may change when gum is used, as gum also competes for water; it means that less water becomes available for WPC and rice flour particles. In such a situation, the storage modulus and loss modulus also increase.

Effect of sucrose

Maache-Rezzoug et al. (1998) has reported that the addition of sugar causes a fall in the viscosity; excess sugar softens the dough due to its physico-chemical role in relation to water and starch. In the present study, an increase in the level of sucrose in rice dough decreases the G' values markedly (Fig. 2) meaning the formation of softer doughs. The addition of sucrose lowers the consistency of bread dough (wheat flour) as evident by the drop in the G' and G'' values (Salvador et al. 2005). In the present study, both G' and G'' decreases; the consistency of

Table 4 Sensory assessment of rice flour doughs

Expt. No.	Hardness		Springiness		Stickiness	
	Physical	Score	Physical	Score	Physical	Score
1	Moderately hard	7.1±0.3 ^f	Little springy	5.8±0.2 ^c	Little sticky	5.8±0.2 ^d
2	Hard	8.0±0.2 ^{hg}	Springy	8.1±0.2 ^f	Nearly non-sticky	2.3±0.1 ^b
3	Soft	4.3±0.2 ^d	Non-springy	1.2±0.1 ^a	Marginally non-sticky	3.9±0.2 ^c
4	Hard	7.9±0.3 ^g	Non-springy	1.2±0.1 ^a	Extremely sticky	8.7±0.2 ^f
5	Moderately hard	6.9±0.2 ^f	Non-springy	1.1±0.2 ^a	Moderately sticky	7.3±0.3 ^e
6	Moderately soft	3.1±0.1 ^c	Little springy	6.1±0.2 ^c	Little sticky	6.1±0.1 ^d
7	Soft	4.1±0.1 ^d	Springy	7.8±0.3 ^e	Moderately sticky	7.0±0.2 ^e
8	Moderately soft	3.1±0.2 ^c	Moderately springy	7.2±0.3 ^d	Nearly non-sticky	2.2±0.2 ^b
9	Moderately soft	3.4±0.3 ^c	Little springy	6.0±0.2 ^c	Highly sticky	8.6±0.4 ^f
10	Forms a thick batter	1±0 ^a	Non-springy	1.3±0.1 ^a	Extremely sticky	8.7±0.3 ^f
11	Hard	8.3±0.1 ^g	Moderately springy	7.2±0.1 ^d	Highly sticky	8.9±0.2 ^f
12	Soft	3.9±0.2 ^{cd}	Springy	7.7±0.4 ^e	Highly sticky	8.7±0.2 ^f
13	Little hard	6.1±0.2 ^e	Moderately springy	7.1±0.2 ^{de}	Little sticky	6.0±0.3 ^d
14	Moderately hard	7.4±0.3 ^f	Little springy	5.9±0.2 ^c	Little sticky	6.2±0.1 ^d
15	Very soft	1.9±0.1 ^b	Non-springy	1.1±0.2 ^a	Extremely sticky	8.8±0.1 ^f
16	Little hard	6.0±0.2 ^e	Little springy	6.3±0.3 ^c	Non-sticky	1.3±0.1 ^a
17	Very hard	8.8±0.3 ^h	Moderately springy	7.0±0.1 ^d	Non-sticky	1.1±0.2 ^a
18	Hard	7.9±0.2 ^g	Moderately springy	7.2±0.2 ^d	Non-sticky	1.4±0.1 ^a
19	Soft	4.4±0.2 ^d	Little springy	6.0±0.1 ^c	Nearly non-sticky	2.0±0.1 ^b
20	Hard	8.1±0.3 ^g	Little springy	5.9±0.3 ^c	Moderately sticky	7.0±0.2 ^e
21	Soft	4.0±0.1 ^d	Little springy	6.1±0.2 ^c	Moderately sticky	7.1±0.3 ^e
22	Hard	8.0±0.2 ^g	Moderately springy	7.3±0.2 ^d	Moderately sticky	6.9±0.1 ^e
23	Hard	7.9±0.2 ^g	Moderately springy	6.9±0.3 ^d	Little sticky	6.3±0.2 ^d
24	Soft	3.9±0.3 ^c	Non-springy	1.0±0.1 ^a	Moderately sticky	7.3±0.2 ^e
25	Soft	3.9±0.2 ^{cd}	Non-springy	1.1±0.2 ^a	Moderately sticky	6.8±0.3 ^e
26	Very hard	8.7±0.4 ^h	Little springy	5.8±0.2 ^c	Moderately sticky	6.9±0.2 ^e
27	Hard	7.9±0.3 ^g	Little springy	6.1±0.2 ^c	Little sticky	5.9±0.2 ^d
28	Soft	4.1±0.3 ^d	Marginally non-springy	4.1±0.2 ^b	Little sticky	5.8±0.4 ^d
29	Hard	7.6±0.4 ^g	Moderately springy	7.3±0.2 ^d	Nearly non-sticky	1.9±0.3 ^b
30	Soft	4.4±0.2 ^d	Little springy	5.7±0.4 ^c	Highly sticky	8.1±0.2 ^f
31	Moderately soft	3.3±0.3 ^c	Moderately springy	7.1±0.2 ^d	Moderately sticky	6.9±0.3 ^e
Dough without additive	Very hard	8.8±0.2 ^h	Springy	8.0±0.2 ^f	Non-sticky	1.4±0.2 ^a

Values are expressed as mean±standard deviation (SD)

Values in the same column with different superscripts differ significantly at $p \leq 0.05$

Scales for

Hardness: 1: Extremely soft; 2: Very soft; 3: Moderately soft; 4: Soft; 5: Neither hard nor soft; 6: Little hard; 7: Moderately hard; 8: Hard; 9: Very hard; 10: Extremely hard

Springiness: 1: Non-springy; 2: Nearly non-springy; 3: Moderately non-springy; 4: Marginally non-springy; 5: Neither non-springy nor springy; 6: Little springy; 7: Moderately springy; 8: Springy; 9: Highly springy; 10: Extremely springy

Stickiness: 1: Non-sticky; 2: Nearly non-sticky; 3: Moderately non-sticky; 4: Marginally non-sticky; 5: Neither non-sticky nor sticky; 6: Little sticky; 7: Moderately sticky; 8: Sticky; 9: Highly sticky; 10: Extremely sticky

dough in terms of η^* also decreases (Fig. 2). Chang et al. (2004) have also reported that the magnitude of G' decreases with an increase in the concentration of sugar in corn starch. The affinity of sucrose for water is associated with a reduction in the availability of water molecules, inhibiting water

absorption by the starch and gluten. The resulting doughs are thus less consistent and their protein networks require longer development times to unfold. However, according to Olkku and Rha (1978), the amount of the hydroxyl groups available for hydrogen bonding of water is not sufficient to

Fig. 4 Principal component analysis (PCA) plot for instrumental rheological indices and sensory attributes. Numbers shown in brackets are the experiment numbers as shown in Table 1

explain water binding of sucrose in competition with starch. Hence, the role of sucrose for modifying the rheological status of doughs is undesirable; however, the addition of sugar is mandatory if sweet taste of the particular finished product is the choice of consumers.

Effect of salt

An increase in salt content in a rice dough decreases both G' and G'' and thus the consistency of dough decreases (Fig. 2). It may be attributed to a decrease in inter-protein hydrophobic interactions, which falls as a result of their effects upon the water addition; this decrease largely depends on the content and quality of the proteins present (Preston 2001). Hence, the tendency of the proteins to aggregate decreases and reduces elasticity. Peressini and Sensidoni (2000) have encountered a little influence of the added NaCl on the rheology of fresh pasta dough. The addition of NaCl causes rheological modification of wheat dough primarily by influencing the structure and formation of the gluten matrix, as visualised by confocal laser scanning microscopy (CLSM) (Beck et al. 2011). These effects are due to the neutralisation of charge repulsion emanating from charged amino acid moieties on the surface of gluten proteins. This charge neutralisation is caused by sodium and chloride ions. A conclusion from this study is that NaCl increases dough stickiness.

The addition of salt causes a decrease in consistency but increases the hydration time particularly at low water levels. The effect of salt on hydration can be related to its competition in absorption of water with the flour. The effect of added water on consistency and hydration is negative. Added water softens the dough and decreases the hydration time, and the energy required for mixing (Galal et al. 1978). When salt is present in the system, it

may increase the amount of free and mobile water by altering the gluten structure in a way that salt occupies the sites once occupied by the bound water (Farahnaky and Hill 2007).

Interrelations

The interrelations between instrumental rheological indices and sensory attributes are important from the point of processing/handling of dough and subsequent applications in developing flattened/sheeted/rolled dough-based products. The sensory attribute hardness indicates the extent of force and energy required to compress or flatten or roll the dough into thin sheets; a high value is unsuitable as it tends to be an energy extensive step. The attribute springiness means the tendency to spring back or regain the initial height after compression processing; a high springiness is thus undesirable if highly thin sheet/product is desirable. On the other hand, stickiness is a serious factor that is detrimental for dough handling and a high extent of stickiness is totally unacceptable for any possible machining of the dough.

Very hard dough results when no additive is used; the dough is springy but not sticky (Table 4). The experiment #10 results in a thick batter in absence of the gum meaning that the presence of xanthan gum is mandatory when the other three ingredients are used; the phase angle in this case is also the highest (about 24°). A high level of WPC also offers a hard dough. The concept of principal component analysis (PCA) has been applied and presented in Fig. 4 to relate the instrumental rheological indices and sensory attributes. Springiness/hardness and phase angle are inversely related meaning that a low value of phase angle can offer more springiness and harder dough.

Conclusions

Raw rice flour dough, in absence of additives, is very hard and exhibits high extent of elasticity or springiness but very little stickiness. The handling properties of rice doughs can be improved by using different additives. The oscillation testing on rice flour doughs indicates that xanthan gum imparts the strongest effect (significant at $p \leq 0.01$) followed by whey protein concentrate (WPC). The effects of these additives are predominantly linear though quadratic effects are also significant in some cases meaning an overall curvilinear behaviour. The sensory panel has an opinion that a moderate hardness of dough in combination with the moderate extent of springiness and low stickiness are the desirable features considering a dough to be flattened/rolled/sheeted/shaped to make different products. The suitable levels of WPC, gum, sugar and salt are 2.5–5.0, 1.25–3.75, 5–10 and 0.5–1.5 %, respectively.

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