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ORIGINAL ARTICLE

Effect of gelatinized-retrograded and extruded starches on characteristics of cookies, muffins and noodles

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Abstract The effect of substitution of wheat flour with gelatinized-retrograded starch (GRS) and extruded starch (ES) at 10 and 20 % levels on characteristics of cookies, muffins and noodles was evaluated. Cookies made by substitution of flour with GRS or ES were lighter in color, showed higher spread ratio and resistant starch (RS) content. Muffins made by substitution of flour with GRS or ES were lighter in color, showed less height, specific volume and gas cells and higher RS content. Muffins containing GRS were less firm while those made by incorporating ES showed higher firmness than those made without substitution. Noodles made with substitution of flour with GRS or ES showed higher RS content and reduced water uptake, gruel solid loss, hardness and adhesiveness. Cookies and noodles prepared with and without substitution of flour with GRS or ES did not show any significant differences in terms of overall acceptability scores.

Keywords Resistant starch · Gelatinized-retrograded starch · Extruded starch · Texture · Sensory attributes

Highlights • Cookies made from flour substituted with gelatinized/extruded starch had higher spread ratio and resistance starch.
• Muffins from flour substituted with gelatinized/extruded starch showed lower volume and higher resistance starch
• Noodles from of flour substituted with gelatinized/extruded starch showed lower cooking time, gruel solids loss and stikiness

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Introduction

Resistant starch (RS) is defined as the sum of starch and products of starch degradation that are not absorbed in the small intestine of healthy individuals (Englyst et al. 1996). Naturally occurring RS (in whole grains, legumes, unripe bananas and potatoes) is considered as dietary fiber while RS which is added to foods for health benefits is classified as functional fibre (Sajilata et al. 2006). RS is widely used as a functional ingredient in foods containing high levels of dietary fibre. RS has great potential to be used in foods due to its potential physiological benefits and unique functional properties (Baixauli et al. 2008a). It behaves physiologically as a fibre (Haralampu 2000) and resulted in increased fecal bulk, reduced colonic pH (Slavin et al. 2009), lower levels of serum cholesterol and triglycerides (Fuentes-Zaragoza et al. 2010), reduced postprandial glycemic and insulinemic responses, which may be useful for the people suffering from diabetes (Tharanathan and Mahadevamma 2003). Traditionally foods rich in fiber have been coarser, denser and less palatable than processed foods but the incorporation of RS does not alter the sensory attributes. However, foods containing RS have small particle size, white appearance, bland flavour and good handling during processing. Additionally, RS showed improved product characteristics, which include crispness, expansion, mouthfeel, color and flavor (Sajilata et al. 2006). Bakery products such as bread, muffins, and breakfast cereals can be prepared by using RS as a source of fibre. The amount of RS used to replace flour depends on the particular starch being used, the application, desired fibre level, and, in some cases, the desired structure-function claims. The incorporation of RS in baked products, pasta products and beverages imparts improved textural properties and health benefits (Premavalli et al. 2006).

Therefore, the objectives of the present study were to investigate the effect of incorporation of gelatinized- retrograded starch

(GRS) and extruded starch (ES) at two different levels (10 and 20 %) on the cookies, muffins and noodles characteristics.

Materials and methods

Cookies, muffins and noodles were prepared using wheat flour variety (HD3086) procured from Indian Agricultural Research Institute (IARI), New Delhi. Starch isolated from kidney bean (IC519877) was gelatinized-retrograded and extruded. The gelatinized-retrograded and extruded starches were added in the products at two different levels (10 and 20 %). Three formulations were prepared for each product using the same quantity of all the ingredients except flour and GRS or ES, which were 100/0, 90/10 and 80/20, respectively.

Preparation of gelatinized-retrograded and extruded starches

RS was added in the form of gelatinized-retrograded and extruded kidney bean starch (IC519877). For gelatinization, starch:water (5:50) were heated at 90 °C for 30 min and slurry was then retrograded by keeping in refrigerator at 4 °C for 24 h. For gelatinization, starch:water (5:50) was heated at 90 °C for 30 min and slurry was then retrograded by keeping in refrigerator at 4 °C for 24 h. For preparation of extruded starches, kidney bean starch was extruded at feed moisture of 24 % at extrusion temperature of 100 °C and screw speed of 100 rpm in a Clextral twin screw extruder. Extruded starch was dried at 40 °C and ground for further use.

Cookies making

Cookies were prepared as per the AACC methods (2000). The recipe used for the preparation of cookies was wheat flour (variable), vanaspati (25.6 g), sugar (52 g), baking powder (3.33 g) and sodium bicarbonate (1.0 g). After mixing of dry ingredients, 13.2 mL of dextrose solution (5.93 %) and water were added and mixed to prepare the dough of desirable consistency. Dough was then sheeted to desired thickness and was cut with cookies cutter of specified diameter (5.7 nm). Cookies were then baked at of 200 °C for 18 min in a preheated oven equipped with rotating racks (National Manufacturing Company, Lincoln, NE, USA). After baking, the cookies were allowed to cool at ambient temperature for 30 min.

Color parameters (L^*, a^* and b^*) of cookies were measured using a Hunter colorimeter (Model D 25 optical Sensor; Hunter Associates Laboratory, Reston, VA, USA). Colour difference (ΔE) between cookies made from flour with and without substitution with GRS and ES were calculated according to the equation $\Delta E = SQRT [(L^* - L^*_n)^2 + (a^* - a^*_n)^2 + (b^* - b^*_n)^2]$.

where L^*, a^*, b^* were parameters for substituted samples and L^*_n, a^*_n, b^*_n were parameters for flour without substitution. The spread ratio (SR) of cookies was determined using the ratio between the thickness and width. The breaking strength of cookies was determined using a texture Analyzer (Stable Microsystems, Crawley, UK) as described earlier (Kaur et al. 2014). The three point break test was used to determine the texture of the cookies. RS content of cookies were determined using the method of Englyst et al. (1992). Sensory analysis was carried out using 9 point hedonic scale. The attributes evaluated were color, texture, crispiness, flavor, aftertaste and overall acceptability (OA).

Muffins making

Muffins were prepared using the recipe described by Shevkani and Singh (2014) with slight modifications. The recipe used for the preparation of muffins was wheat flour (variable), refined soybean oil (50 g), sugar (50 g), egg albumin (50 g), milk (50 g) and baking powder (3.33 g). Flour, sugar and baking powder were mixed for 1 min using a pin mixer. Egg, milk and oil (previously mixed) were then slowly poured and mixed for another 5 min. The batter (30 g) was poured into the mold and baked at 180 °C for 25 min in a baking oven (National Manufacturing Company, USA). After removing from the oven, the muffins were cooled to room temperature, sealed in air tight jars and stored at room temperature for 24 h. The characteristics of muffins (weight, volume, height and color of crust) were determined within 24 h after baking. Muffin volume was measured by rape-seed displacement method of Griswold (1962). Height was measured with a digital caliper from the bottom to the highest point of the muffin. Color of the crust was measured using a Hunter colorimeter (Model D 25 optical Sensor; Hunter Associates Laboratory, Reston, VA, USA). Colour difference (ΔE) between muffins made from flour with and without substitution with GRS and ES were calculated as described above in cookies. Texture was measured using texture analyzer (Stable Micro systems, Surrey, UK) as described earlier (Shevkani and Singh 2014). The cubes (12.5 mm3) were subjected to compression (50 %) and evaluated for firmness (F), cohsiveness (Coh), gumminess (Gum) and springiness (Sprin). RS content of muffins was determined as described earlier (Englyst et al. 1992). Sensory analysis was done using 9 point hedonic scale. The attributes evaluated were color, F, flavor, aftertaste and OA of muffins.

Noodles making

Dough of optimum desirable consistency was prepared by mixing flour (100 g) or flour with ES or GRS with water in a dough mixer. The noodles were prepared by extruding the dough through a hand operated extruded machine (Gagan Udyog Pvt. Ltd. Jalandhar), dried in oven at 40 °C (Universal hot air oven) and stored in sealed polyethylene bags.

For determination of cooking time (CT), noodles (2.5 g) were cooked in boiling distilled water (50 mL) until the white core was disappeared as judged by squeezing the noodles between two glass slides. Cooked weight, gruel solid loss (GSL) and water uptake (WU) were determined as described by Galvez and Resurreccion (1992) with minor modifications. Noodles (2.5 g) were cooked in boiling water (50 mL) for 5 min until disappearance of white core. The cooked noodles were drained for about 2 min, rinsed with distilled water and cooked weight was determined by weighing wet mass of noodles. The cooked noodles were drained and rinsed with distilled water (50 mL). The gruel solid loss was determined by evaporating the cooking water to dryness in a pre-weighed petri dish by keeping it an oven at 110 °C, overnight which were then cooled in a desiccator and reweighed. The water uptake is the difference between the weight of cooked noodle and uncooked noodles, expressed as the percentage of weight of uncooked noodles. Cooked noodles were rinsed with water and then weighed, indicating the amount of water absorbed by the noodle during the process of cooking. Noodles characterstics were determined as described earlier (Kaur et al. 2016).

Textural properties of noodles were analyzed using the method described earlier by Yadav et al. (2014) with some modifications using texture analyzer (Stable Microsystems, Crawley, UK). Noodles (10 g) were cooked in boiling distilled water (250 mL) for optimum time and then rinsed with cold water. The textural properties of cooked noodles were evaluated within 5 min after cooking using Texture Analyzer equipped with 1 Kg load cell. A set of five strands of cooked noodles was placed parallel at the center of a heavy duty platform (HD P/90) and subjected to compression (70 %) using a 75 mm diameter aluminium probe (P/75) at a constant speed of 1 mm s^{-1}. Various textural parameters analyzed were hardness (H), Coh, Gum, Sprin and adhesiveness (Adh). RS content of cooked noodles was determined using the method of Englyst et al. (1992). The various sensory attributes (stickiness, chewiness, H, appearance, aftertaste and OA) of noodles were evaluated using 9 point hedonic scale.

Statistical analysis

The statistical significance of data was determined using Analysis of variance, separately for products made with incorporation of GRS and ES.

Results and discussion

Cookie characteristics

Hunter color parameters, SR, rupture force and RS of cookies made from flour with and without substitution with GRS and ES are shown in Table 1. Cookies without substitution showed *L**, *a** and *b** values of 60.0, 9.2 and 30.2, respectively. *L**, *a** and *b** values ranged from 63.4 to 64.4, 10.0 to 11.4 and 31.5 to 35.2, respectively for the cookies substituted with GRS while for those substituted with ES ranged from 63.1 to 63.3, 8.5 to 8.6 and 28.5 to 29.5, respectively. Cookies made without substitution were darker in color as compared to those made by substitution with GRS or ES. This could be attributed to dilution of proteins. Cookies substituted with ES were darker in color as compared to those substituted with GRS. Earlier cassava starch showed reduced luminosity after extrusion indicating that extrusion cooking led to darker starch as compared to unextruded starch (Leonel et al. 2009). The level of substitution of flour with GRS significantly affected the *L** value of cookies. Laguna et al. (2011) reported that short dough biscuits made with RS rich ingredient were lighter in color (*L**-70.4 to 71.8, *a**- 3.5 to 5.0 and *b**- 22.6 to 30.2) as compared to those made without RS (*L**-66.0, *a**- 4.7 and *b**-30.6). The ΔE for cookies made from flour substituted with GRS was higher than those substituted with ES. The ΔE for cookies made from flour substituted with GRS varied from 3.72 to 7.01 against between 3.29 and 3.76 for those made by substitution of flour with ES. The results reflected that redness was higher in cookies made by substitution with GRS than those made by substitution with ES (Miller et al. 1997).

Cookies made with GRS or ES had higher SR (13.2 to 20.2) as compared to those made without any substitution (12.5). This could be associated with more syrup formation as well as dilution of wheat proteins in the cookies made from flour substituted with GRS and ES. Diameter and protein content were reported to be inversely correlated (Leon et al. 1996) and thus the SR also. Therefore dilution of proteins on substitution of flour with GRS or ES increased the availability of water for sugar to form syrup and this led to higher spreading of dough during baking. Wheat protein forms a web in cookie dough during baking and the gluten passes through an apparent glass transition, thereby, gaining mobility that allowed interaction and formation a web. Increase in the viscosity of dough due to the formation of continuous gluten web may have stopped the flow of cookie dough (Miller and Hoseney 1997). The substitution of flour with ES caused greater changes in SR (17.4 to 20.2) as compared to GRS (13.2 to 16.1) (Table 1). This could be associated with higher water content present in the dough of the former as more water present in the dough caused more sugar to be dissolved during mixing, thereby reducing the initial viscosity of dough and thus leading to spreading at a faster rate during baking. SR was

Table 1 Effect of substitution of flour with gelatinized-retrograded and extruded starch on cookie characteristics

Blend	Substitution level (%)	Color values			ΔE	SR	Rupture force (N)	RS (%)
		L^*	a^*	b^*				
Flour	0	60[a]	9.2[a]	30.2[a]		12.5[a]	52.7[c]	1.2[a]
Flour + GRS	10	63.39[b]	10.0[b]	31.5[b]	3.72	13.2[b]	27.6[b]	3.8[b]
Flour + GRS	20	64.4[c]	11.4[c]	35.2[c]	7.01	16.1[c]	16.9[a]	6.7[c]
F value	-	62.90	50.32	76.22		5.40	155.72	35.28
Pooled S.D.		0.50	0.27	0.51		1.44	2.55	0.81
Flour	0	60[a]	9.2[b]	30.2[b]		12.5[a]	52.7[b]	1.2[a]
Flour + ES	10	63.14[b]	8.5[a]	29.5[a]	3.29	17.4[b]	31.6[a]	7.8[b]
Flour + ES	20	63.3[b]	8.6[a]	28.5[a]	3.76	20.2[c]	29.8[a]	9.1[c]
F value	-	78.39	13.96	22.22		23.76	81.78	238.12
Pooled S.D.		0.37	0.18	0.37		1.37	2.44	0.47

Means with similar superscripts in a column do not differ significantly ($p \leq 0.05$). GRS- gelatinized-retrograded starch, ES-extruded starch, SR-spread ratio, RS-resistant starch, ΔE- colour difference between cookies made from flour with and without substitution with GRS and ES

significantly affected by substitution of flour with GRS and ES as well as the level of substitution. The increase in SR with substitution of GRS and ES was also being attributed to reduction in consistency of dough as lower consistency allows faster cookie spread.

Cookies made without substitution required higher rupture force (52.7 N) as compared to 16.9–27.6 N and 29.8–31.6 N, respectively, for those substituted with GRS and ES (Table 1). Rupture force was significantly affected by substitution of flour and level used for substitution. This could be attributed to comparatively high protein content of wheat flour which required more water to obtain good cookie dough, and thus cookies tend to be hard (Hoojjat and Zabik 1984) and thus less amount of water is available for syrup formation. With increase in the substitution level of GRS or ES, the resistance to rupture was significantly reduced which could be because of higher SR. Cookies made by substitution of flour with ES required greater force to rupture in comparison to those made by substitution with GRS. The higher value of rupture force in cookies made without substitution indicated a more interconnected, structured matrix, which could be due to the higher level of wheat proteins (Laguna et al. 2011). Earlier a decrease in force at break from 5.9 to 7.5 N for biscuits made by substitution of wheat flour with RS (Hi- maize 260) than those made without RS (17.2 N) was reported (Laguna et al. 2011).

Cookies made by substitution with GRS or ES showed higher RS content varying from 3.8 % to 6.7 % and 7.8 % to 9.1 %, respectively as compared to 1.2 % for those made without substitution. RS content of cookies made by substitution with ES was higher as compared to those made with GRS which could be associated with the formation of amylose-lipid complexes during extrusion (Singh et al. 2010). Similar to our results, biscuits prepared with wheat flour were reported to have lower RS content (0.49 g/100 g) than those made with RS (3.9–11.2 g/100 g) (Laguna et al. 2011).

Effect of substitution of flour with GRS and ES on sensory attributes of cookies is shown in Table 2. Sensory analysis of cookies made with and without substitution did not show any significant differences. Texture scores were significantly higher for cookies made by using GRS or ES as compared to those made without substitution. Substitution of flour with GRS or ES brought positive changes in the textural attributes of cookies. Substitution with GRS or ES did not affect the OA scores of cookies. With increase in level of substitution, sensory scores for color reduced. Sensory analysis revealed that cookies with high RS content can be prepared by substitution of wheat flour with GRS or ES at 10 to 20 % levels without any adverse effect on sensory attributes. Similar results were observed for short dough biscuits made with RS where the acceptance scores of biscuits made with or without RSR1 (20 %) did not significantly affected any of the measured sensory attributes, however, increase in the level of substitution significantly affected them (Laguna et al. 2011).

Muffin characteristics

Hunter color parameters, height, specific volume, textural characteristics and RS content of muffins made from flour with and without substitution of GRS and ES are shown in Table 3. Similar to cookies, muffins prepared by substitution of wheat flour with GRS or ES were lighter in color (L^*- 55.7 to 59.5) as compared to those made without substitution (L^*- 55.2). Lighter color of muffins made by substitution of flour with GRS and ES could be attributed to dilution of proteins, thus less protein was available for participation in Maillard reaction and consequently resulted in less browning.

Table 2 Effect of substitution of flour with gelatinized-retrograded and extruded starch on sensory scores of cookies

Blend	Substitution level (%)	Color	Texture	Crispiness	Flavor	Aftertaste	Overall acceptability
Flour	0	8.2^b	7.5^a	7.5^a	8.0^a	8.2^a	8.2^a
Flour + GRS	10	7.3^a	8.5^b	8.2^b	8.0^a	8.0^a	8.3^a
Flour + GRS	20	7.2^a	8.5^b	8.2^b	8.0^a	8.0^a	8.3^a
Flour	0	8.2^b	7.5^a	7.5^a	8.0^a	8.2^a	8.2^a
Flour + ES	10	7.5^a	7.7^a	7.7^a	8.0^a	8.0^a	8.3^a
Flour + ES	20	7.3^a	7.7^a	7.7^a	8.0^a	8.0^a	8.3^a

Means with similar superscripts in a column do not differ significantly ($p \leq 0.05$). GRS- gelatinized-retrograded starch, ES-extruded starch

Luminosity increased significantly with increase in level of substitution. The *a** and *b** values were significantly affected by substitution of flour with both GRS or ES as well as level of substitution. Muffins made with RS were reported to be lighter in color (*L**- 77.1 to 80.1) than those made without RS (*L**- 75.9) and was well correlated with the diluting effect of RS on the pigmented ingredients in the recipe (Baixauli et al. 2008b). The ΔE for muffins made from flour substituted with GRS was higher than those substituted with ES. The ΔE for noodles made from flour substituted with GRS varied from 0.54 to 5.41 against between 0.62 and 2.50 for those made by substitution of flour with ES. The results reflected that redness was higher in noodles made by substitution with GRS than those made by substitution with ES.

The height attained by muffins during baking is one of the desirable characteristics. Wheat flour muffins showed significantly higher rise during baking (35.2 mm) as compared to those made by substitution with GRS or ES (32.3–33.7 mm). Baixauli et al. (2008c) also reported that with increase in the level of RS, the height of muffins was reduced from 4.7 cm to 3.8–4.6 cm. Wheat flour muffins had higher specific volume as compared to those made by substitution with GRS or ES. The higher specific volume of the former could be attributed to the higher protein content leading to enhanced viscoelasticity of batters, thereby causing better incorporation and stability of air bubbles during baking. Proteins got diluted by substitution with GRS or ES, thereby causing some structural changes in the muffins as the proteins act as emulsifiers by forming a film or skin around oil droplets and prevent structural changes such as coalescence or creaming (Boye et al. 2010). Both height and specific volume of muffins reduced with increase in level of substitution of wheat flour with GRS or ES due to reduction in protein content. Earlier, Singh et al. (2016) reported that wheat flours with higher protein content resulted into muffins with greater air spaces and lower firmness. Similarly, a reduction in the volume and height of the bakery product was observed after addition of fibre to the ingredients (Peressini and Sensidoni 2009).

Number of gas cells was reduced on substitution of wheat flour with GRS or ES which could be attributed to the dilution of gluten matrix that resulted into reduction in gas retention

Table 3 Effect of substitution of flour with gelatinized-retrograded and extruded starch on muffins characteristics

Blend	Level of substitution (%)	Color values			ΔE	Height (mm)	Specific volume (mL/g)	F (N)	Coh	Gum	Sprin	RS (%)
		L^*	a^*	b^*								
Flour	0	55.2^a	18.6^b	39.4^b		35.2^c	2.66^b	4.2^c	0.66^a	2.8^c	0.88^c	2.5^a
Flour + GRS	10	55.7^b	18.6^b	39.2^a	0.54	33.6^b	2.55^a	3.5^b	0.64^a	2.2^b	0.86^a	3.5^b
Flour + GRS	20	59.5^c	16.6^a	42.0^c	5.41	32.6^a	2.47^a	2.4^a	0.72^b	1.7^a	0.87^b	4.5^c
F value	-	54.91	17.56	48.39		19.31	2.46	20.22	2	34.10	0.57	5.96
Pooled S.D.		0.54	0.48	0.39		0.51	0.11	0.37	0.05	0.19	0.05	0.88
Flour	0	55.2^a	18.6^b	39.4^b		35.2^c	2.66^b	4.2^a	0.66^b	2.8^a	0.88^b	2.5^a
Flour + ES	10	55.7^a	18.4^b	39.7^c	0.62	33.7^b	2.41^b	5.8^b	0.64^b	3.8^b	0.83^a	3.7^b
Flour + ES	20	56.4^b	16.7^a	38.3^a	2.50	32.3^a	2.23^a	8.2^c	0.56^a	4.6^c	0.80^a	4.7^c
F value	-	2.46	11.50	29.68		141.66	25.95	63.87	39.86	37.78	1.48	7.05
Pooled S.D.		0.65	0.52	0.24		0.21	0.07	0.44	0.02	0.25	0.05	0.84

Means with similar superscripts in a column do not differ significantly ($p \leq 0.05$). GRS-gelatinized-retrograded starch, ES-extruded starch, F-firmness, Coh-cohesiveness, Gum-gumminess, Sprin-springiness, RS-resistant starch, ΔE- colour difference between muffins made from flour with and without substitution with GRS and ES

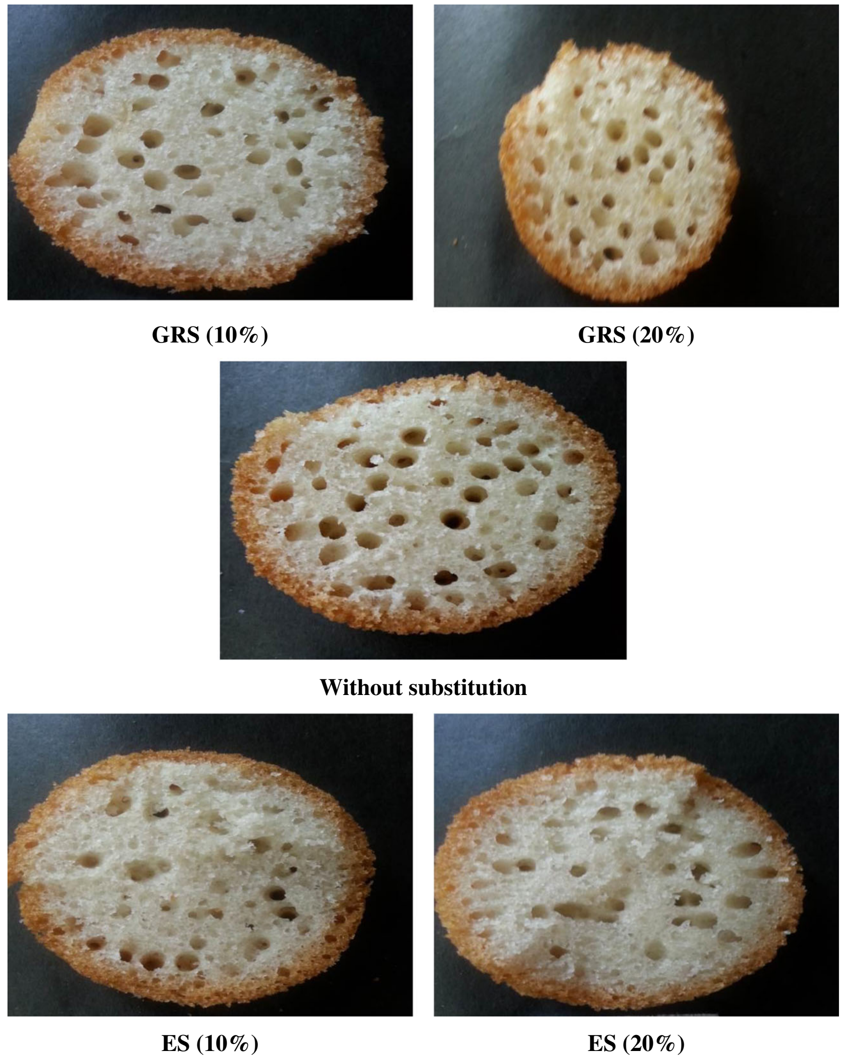

Fig. 1 Cross-section of muffins representing air-cells in those made with and without substitution of wheat flour with GRS (gelatinized-retrograded starch) and ES (extruded starch) at two different levels (10 and 20 %)

capacity (Fig. 1). Substitution with ES caused greater reduction in the number of air cells than GRS. Baixauli et al. (2008c) reported significantly lower number of gas cells in muffins made with the addition of RS as compared to those made without RS (Baixauli et al. 2008c).

F of muffins made without substitution was 4.2 N against 2.4–3.5 N and 5.8–8.2 N, respectively, for those substituted with GRS and ES (Table 3). Increase in firmness on substitution with ES could be associated to its low gas retention ability and specific volume. F of muffins increased with increase in level of substitution with ES and decreased with GRS. Coh is defined as the resistance of food to traction (Majzoobi et al. 2013). Muffins made from flour substituted with ES showed comparatively lower Coh than those made without substitution. Muffins made by substitution with GRS showed lower Gum than those made without substitution or substitution with ES. Sprin is desirable in muffins and has been associated with fresh, aerated and elastic product (Sanz et al. 2009). Reduced Sprin on substitution with ES could be associated with less number of air cells due to less aerated structure. A significantly lower F (3–3.5 N), Coh (~0.7) and Sprin (~0.6–0.8) was observed for muffins containing RS than those made without RS (F; 4 N; Coh- 0.7; Spin- 0.9) (Baixauli et al. 2008b). Results reflected that substitution of wheat flour with GRS improved the texture of muffins as revealed by reduced F resulting in softer and tender crumb. On the contrary, substitution with ES led to increased F and reduced Sprin reflecting the harder and less aerated muffins.

RS content of muffins increased from 2.5 % for those made without substitution to 3.5 to 4.7 % for those substituted with GRS or ES. Similar to cookies, RS content was higher in muffins made by substitution with ES as compared to those substituted with GRS which could be associated with the formation of amylose-lipid complexes during extrusion (Singh et al. 2010). RS content of muffins was significantly affected by substitution of wheat flour with GRS or ES and the level of substitution. The level of RS increased with the level of substitution. RS content of muffins made by replacement of flour with RS at different levels (5–20 %) varied between 2.79 g/100 g and 7.34 g/100 g (Baixauli et al. 2008a).

Effect of substitution of flour with GRS and ES on sensory attributes of muffins is shown in Table 4. Muffins made from flour substituted with GRS and ES showed lower sensory scores for color than those made without substitution. Scores of F were higher for muffins made by substitution with GRS than those made without or with ES. ES adversely affected the textural attribute of muffins as it led to increased firmness. Substitution of flour did not significantly affect flavor and aftertaste of muffins. OA scores of muffins was significantly affected by the substitution of flour with ES which was primarily associated with lower F scores and less spongy texture due to low gas retention ability. Muffins made by substitution with GRS showed the highest OA scores followed by those made without substitution and then that with ES. With increase in the level of substitution of ES, F scores were significantly reduced. Sensory analysis of cake like muffins made with RS2 and RS3 showed similar results where RS improved the texture by imparting tenderness to the crumb (Yue and Waring 1998). Baixauli et al. (2008b) reported significant differences in textural attributes and appearance of the muffins made with addition of RS.

Noodles' characteristics

Cooking characteristics, textural parameters and RS content of noodles made from flour with and without substitution of GRS and ES is shown in Table 5. Noodles made without substitution showed higher CT than those made by substitution with GRS (5–5.5 min) and ES (4.5–5 min). Comparatively lower CT of the noodles substituted with GRS and ES could be associated with dilution of wheat protein. The disrupted and gelatinized starch granules in GRS and ES may have also contributed to reduction in CT. CT of instant noodles made from flour was reported to be higher (2.2–3.4 min) than those made by substitution with buckwheat flour (1.2–2.5 min) by Choy et al. (2013). Similar values of CT (4 to 5 min) of noodles made from flour from different wheat varieties were reported (Kaur et al. 2015).

WU was maximum for flour noodles (183.7 %) followed by those made by substitution with GRS (155.4 to 176.2 %) and ES (143.8 to 163.8 %). Lower WU of noodles made from flour substituted with GRS or ES than those made without any substitution could be associated with the structural modification of the starch during gelatinization and extrusion cooking. WU indicates the degree of noodle hydration which affects the eating quality of noodles (Yadav et al. 2011). Rehydration (%) of instant noodles made from wheat flour was reported to be higher (216.9–222.9 %) than those made by substitution with buckwheat flour (189.9–206.1 %) by Choy et al. (2013).

GSL was maximum for flour noodles (19.6 g/100 g) followed by those made from flour substituted with GRS (16.0 to 16.6 g/100 g) and ES (14.7 g/100 g) (Table 5). It reflected that noodles made by substitution of flour with GRS or ES had better structural integrity and did not disintegrate during cooking. Higher GSL of noodles made without substitution could be associated with its higher CT as amylose swell more during boiling in water due to hydration of amorphous regions and thus networks formed were subsequently degraded with increased CT thereby increasing the amylose leaching to the cooking water (Wang et al. 2014). Cooking loss indicates the ability of the noodles to maintain structural integrity during cooking process. Higher cooking losses are undesirable as it reflects the higher starch solubility, resulting in turbid cooking water, low cooking tolerance and sticky mouthfeel (Jin et al. 1994). Both WU and GSL were significantly affected by the substitution of flour with GRS or ES but level of substitution significantly affected the WU only. Pigeon pea starch noodles with higher CT were reported to have higher cooking losses as compared to rice starch noodles (Yadav et al. 2011). Similar to our results, supplementation of flour with wheat bran also resulted in reduced cooking losses of dry noodles (7.6–9.2 %) (Song et al. 2013).

Noodles made from flour without substitution showed higher values for all the textural parameters (H-6.7 N, Coh-0.92, Gum-6.3, Sprin-0.92, Adh-0.10) as compared to those made by substitution with GRS or ES (H-2.9 to 3.8 N, Coh-0.74 to 0.80, Gum-2.1 to 3.0; Sprin-0.88 to 0.92 and Adh-0.03 to 0.08). Higher values of the former could be related to higher protein content which was diluted upon substitution of flour with GRS or ES thus impairing the gluten matrix, leading to weakening of

Table 4 Effect of substitution of flour with gelatinized-retrograded and extruded starch on sensory scores of muffins

Blend	Level of substitution (%)	Color	Firmness	Flavor	Aftertaste	Overall acceptability
Flour	0	8.3^{b}	7.8^{a}	8.0^{a}	8.2^{a}	8.2^{a}
Flour + GRS	10	7.8^{a}	8.3^{b}	8.0^{a}	8.0^{a}	8.3^{a}
Flour + GRS	20	7.5^{a}	8.7^{b}	8.0^{a}	8.0^{a}	8.7^{b}
Flour	0	8.3^{b}	7.8^{b}	8.0^{a}	8.2^{a}	8.2^{c}
Flour + ES	10	8.0^{a}	7.5^{b}	8.0^{a}	8.0^{a}	7.7^{b}
Flour + ES	20	7.8^{a}	6.7^{a}	8.0^{a}	8.0^{a}	7.0^{a}

Means with similar superscripts in a column do not differ significantly ($p \leq 0.05$). GRS- gelatinized-retrograded starch, ES-extruded starch

Table 5 Effect of substitution of flour with gelatinized-retrograded and extruded starch on noodles' characteristics

Treatment	Level of substitution (%)	CT (min)	WU (%)	GSL (g/100 g)	H (N)	Coh	Gum	Sprin	Adh	RS (%)
Flour	0	6^a	183.7^c	19.6^b	6.7^c	0.92^c	6.3^c	0.92^b	0.10^b	0.7^a
Flour + GRS	10	5^a	176.2^b	16.6^a	3.8^b	0.80^b	3.0^b	0.92^b	0.08^b	2.6^b
Flour + GRS	20	5.5^a	155.4^a	16.0^a	2.9^a	0.75^a	2.1^a	0.88^a	0.05^a	2.7^b
F value	-	-	26.29	20.09	21.93	1.88	10.70	3.07	15.38	34.54
Pooled S.D.		0.0	5.81	0.73	0.79	0.17	1.34	0.03	0.02	0.35
Flour	0	6^a	183.7^c	19.6^b	6.7^b	0.92^c	6.3^b	0.92^a	0.10^b	0.7^a
Flour + ES	10	4.5^a	163.8^b	14.7^a	3.7^a	0.79^b	3.0^a	0.92^a	0.04^a	2.2^b
Flour + ES	20	5^a	143.8^a	14.7^a	3.4^a	0.74^a	2.5^a	0.90^a	0.03^a	2.5^b
F value	-	-	66.19	69.43	12.76	0.68	5.96	0.11	51.72	9.60
Pooled S.D.		0.0	4.02	0.64	0.92	0.13	1.49	0.05	0.01	0.57

Means with similar superscripts in a column do not differ significantly ($p \leq 0.05$). GRS-gelatinized-retrograded starch, ES-extruded starch, CT-cooking time, WU-water uptake, GSL-gruel solid loss, H-hardness, Coh-cohesiveness, Gum-gumminess, Sprin-springiness, Adh-adhesiveness, RS-resistant starch

noodle texture (Ritthiruangdej et al. 2011). Protein content of wheat flour had a positive correlation with textural properties including H, Coh, Gum and chewiness (Hu et al. 2007). Textural properties of noodles were significantly affected by substitution of flour with GRS or ES as well as level of substitution. Similar to our results, substitution with buckwheat flour led to reduced H (12.6–17.2 N) and Coh (0.54–0.60) of instant noodles as compared to those made with wheat flour only (H-16.1-18.4 N and coh-0.60) (Choy et al. 2013).

Noodles made by substitution of flour with GRS or ES showed higher RS content varying from 2.6 to 2.7 % and 2.2 % to 2.5 %, respectively as compared to those made without substitution (0.70 %). It reflected that gelatinization-retrogradation process and extrusion cooking led to increased levels of RS which could be associated with structural modifications of starch. Moreover, extrusion cooking may have led to the formation of amylose-lipid complexes thereby increasing the level of RS. Substitution of flour with GRS or ES significantly affected the RS content of noodles but no significant differences were observed with the level of substitution. This is in agreement to the results where RS content of wheat flour noodles increased with addition of β-glucan (4.8 %), banana flour (12.3 %) and their combination (14.4 %) as compared to those made without addition (3.7 %) (Choo and Noor Aziah 2010). Also, the addition of unripe banana flour to wheat flour showed higher RS content (2.1–4.2 %) than noodles made without addition (0.40 %) (Ritthiruangdej et al. 2011).

Effect of substitution of flour with GRS and ES on sensory attributes of noodles is shown in Table 6. Scores of sensory analysis revealed no significant differences in sensory attributes except for H of noodles with 20 % GRS. Noodles made by substitution of flour with GRS or ES showed comparatively higher scores for H and stickiness than those made without substitution, reflecting that the substitution led to improved noodle texture. Amongst the noodles, appearance and OA scores did not differ significantly indicating that substitution with GRS or ES improved the texture of noodles without altering rest of the sensory attributes which shows a great potential for making high RS noodles.

Conclusion

Cookies made by flour substituted with GRS or ES were lighter in color and showed higher SR and RS content and were softer as compared to those made without substitution. Muffins made

Table 6 Effect of substitution of flour with gelatinized-retrograded and extruded starch on sensory scores of noodles

Treatment	Level of substitution (%)	Appearance	H	Stickiness	Chewiness	Aftertaste	Overall acceptability
Flour	0	8.5^a	8.3^a	8.3^a	8.3^a	8.3^a	8.3^a
Flour + GRS	10	8.7^a	8.5^a	8.3^a	8.5^a	8.3^a	8.5^a
Flour + GRS	20	8.5^a	8.8^b	8.5^a	8.7^a	8.3^a	8.7^a
Flour	0	8.5^a	8.3^a	8.3^a	8.3^a	8.3^a	8.3^a
Flour + ES	10	8.5^a	8.5^a	8.7^a	8.5^a	8.3^a	8.5^a
Flour + ES	20	8.5^a	8.7^a	8.7^a	8.7^a	8.3^a	8.7^a

Means with similar superscripts in a column do not differ significantly ($p \leq 0.05$). H-hardness, GRS- gelatinized-retrograded starch, ES-extruded starch by substitution of flour with GRS or ES showed high RS content, light color, reduced height, specific volume and number of gas cells as compared to those made without substitution. Muffins made with GRS showed improved textural properties as compared to those made with or without ES. Substitution of flour with ES increased the firmness of muffins. Noodles made with GRS or ES showed lower CT, WU, GSL, H and stickiness and higher RS than those made without substitution. Sensory analysis revealed that substitution of flour with GRS or ES did not significantly affect the flavor, aftertaste and OA of cookies and noodles while OA of muffins was significantly altered upon substitution. Cookies, muffins and noodles with high RS content can be prepared by substitution of flour with GRS or ES up to 20 % level without significantly affecting the sensory attributes.

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