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Effect of different resistant starch sources and wheat bran on dietary fibre content and *in vitro* glycaemic index values of cookies

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A R T I C L E I N F O

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A B S T R A C T

Cross-linked starches produced in lab-scale from corn and wheat starches with TDF contents of 80.4% and 83.6% were used in cookie formulation to obtain high fibre and low glycaemic index (GI) cookies. Different resistant starch (RS) sources including and wheat bran were also used for comparison. RS sources were added into the formulation at the levels of 25, 50 and 75%. Overall cookie quality (spread ratio, hardness, colour) results showed that among the RS sources and wheat bran, lab-scale produced cross-linked wheat starch (XL-W) had an improving effect on cookie quality, whereas the other sources had detrimental effect. Cookie samples supplemented with XL-W had the highest total dietary fibre (TDF) contents regardless of the addition level. High levels of TDF content were also observed with the wheat bran supplemented cookie samples; however, quality of these cookies were low. RS and wheat bran supplementation caused significant decrease in the *in vitro* GI of the cookies and the lowest GI value was achieved with the cookie supplemented with XL-W. This study proved that XL-W produced in this study can be used as an alternative ingredient to produce high fibre and low GI cookies without any deteriorative effect on the quality.

1. Introduction

Starch is the major dietary source of carbohydrates and a component of dietary fibre (DF). It is classified into three groups: rapidly digestible starch, slowly digestible starch and resistant starch (Englyst et al., 1992). Resistant starch (RS) describes a small fraction of starch which is resistant to hydrolysis of digestion enzymes in the small intestine and may be fermented by gut microbiota in the large intestine (Ashwar et al., 2016). RS is categorized into five fractions: RS1, physically inaccessible starch granules (e.g. in whole or coarse ground grains, seeds or legumes); RS2, native starch granules (e.g. in potato and green banana); RS3, retrograded starch fractions (e.g. in boiled potatoes, bread crumb); RS4, chemically modified starches (e.g. starch esters, starch ethers, cross-linked starches) (Birt et al., 2013; Fuentes-Zaragoza et al., 2010) and RS5, amylose-lipid complexes (Fuentes-Zaragoza et al., 2010). In general, RS has small particle size, white colour and bland flavour. The physical properties of RS such as low water holding capacity, high water binding capacity and processes advantages as less affecting the sensory characteristics of final products with better appearance, texture and mouthfeel than do commercial fibres, makes it a functional ingredient in food processing (Fuentes-Zaragoza et al., 2010). In addition to its functional properties, RS has attracted the attention of nutritionists because of its potential health benefits. RS is fermented by colonic microbiota forming short chain fatty acid and thus positively affecting colonic health (Ashwar et al., 2016), and consumption of RS reduces postprandial glycaemic and insulinemic responses improving the control of obesity and diabetes (Fuentes-Zaragoza et al., 2010).

RS has gained interest of food processers due to advantages mentioned above. Heat and moisture applications generally decrease RS1 and RS2 contents, but may form RS3 (Fuentes-Zaragoza et al., 2010), while in some studies it is reported that the RS3 formation was decreased under high shear extrusion (Haralampu, 2000). RS4 shows stability during processing and the DF content of the final product can be increased up to 100% with addition of RS4 (Woo et al., 2009). RS4

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absorbs nearly same amount of water as wheat flour and can be partially replaced in bakery products without changing water absorption, mixing time, and baking time of dough substantially (Woo et al., 2009). Thus, it is considered a preferred source of fibre for bakery products such as bread (Maningat et al., 2005; Yeo and Seib, 2009) and cookies (Yeo and Seib, 2009).

Cookies are wheat-based snacks consumed with an increasing trend. They gain attraction due to their ready to eat nature, great nutritional quality, availability in various pleasant tastes and prolonged shelf life (Devi and Khatkar, 2016). Thus, they can serve as important carriers of nutrients such as DF. With the increased awareness of health benefits of consumption of DF, there is a growing interest in developing foods enriched with RS as a DF source which does not have any detrimental effect on food quality (Birt et al., 2013).

In the view of the current literature, there are a lot of publications about the effects of RS2 and RS3 on bakery products, but there is little information about the effect of RS4 on cookie quality. We have previously investigated the optimum reaction conditions (temperature and pH) for the preparation of cross-linked corn and wheat starches with high RS content and a permissible phosphorus level of <0.4% using an experimental design. It was shown that the optimal cross-linking reaction conditions to obtain maximum RS content (with a phosphorus level less than 0.4%) were 38 °C, pH 12 for cross-linked wheat starch and 70 °C, pH 12 for cross-linked corn starch (Kahraman et al., 2015). The aim of this study was to investigate the effect of cross-linked corn or wheat starches supplementation on the cookie quality. In order to compare the effects of these lab-scale produced cross-linked starches with other commercial RS samples, Hylon VII (RS2), Novelose330 (RS3), Fibersym (RS4) were used in cookie production at the same levels. Wheat bran was also used to compare the effects of DF and RS sources on cookie quality.

2. Materials and methods

2.1. Materials

Normal corn starch, high amylose corn starch (Hylon VII) and Novelose 330 from National Starch Chemical Co. (Bridgewater, NJ, ABD), normal wheat starch and Fibersym from MGP Ingredients (Atchison, KS, ABD) were used in the study. Wheat bran was obtained from Central Research Institute for Field Crops (Ankara, Turkey). Bran sample was ground to pass 425 μm sieve prior to the cookie production. The percentages of the material remaining on the 425, 212 and 106 μm sieves were 11.9%, 32.1% and 23.2%, respectively. Flour and the other ingredients used in cookie formulation were supplied from a cookie processing company (Ulker Co., Ankara, Turkey).

2.2. Flour characterization

Moisture content of the starch samples and cookie flour were determined using AACCI Method of No. 44-15A. Ash, wet gluten and protein contents, sedimentation and falling number values of the cookie flour were determined using the AACCI Methods of No. 08-01, 38-10, 46-30, 56–60 and 56–81, respectively (AACCI, 2000).

Farinograph characteristics were determined in accordance with Approved Method 54-21 (AACCI, 2000). From the Farinograph curves, the water absorption (% of water required to yield a dough consistency of 500 BU), development time (time to reach consistency of 500 BU), softening degree and stability were obtained.

Dough mixing and pasting behaviours of the flour sample were also studied using the Mixolab (Chopin Technologies Villeneuve La Garenne, France). The “Chopin” protocol was used as followed: initial equilibrium at 30 °C for 8 min, heating to 90 °C over 15 min (at a rate of 4 °C/min), holding at 90 °C for 7 min, cooling to 50 °C over 10 min (at a rate of 4 °C/min) and holding at 50 °C for 5 min. The mixing speed was kept constant at 80 rpm.

2.3. Production of cross-linked starches

In our previous study, the effect of temperature and pH on the yield of resistant starch (RS) content of wheat and corn starches was investigated (Kahraman et al., 2015). According to that study, the optimum reaction temperature to obtain the highest RS content was found to be 38 °C and 70 °C for wheat and corn starches, respectively. The optimum pH values were found to be 12 for both of the starches. The cross-linked wheat and corn starches used in cookie production in the present study were prepared according to Kahraman et al. (2015) at optimum reaction conditions (38 °C at pH 12 and 70 °C at pH 12 for corn and wheat starches, respectively).

2.4. Solubility and water binding capacity

Solubility and water binding capacity (WBC) of starch samples and wheat bran were determined according to the method described by Ozturk et al. (2009). For each sample, 0.5 g was added to 5 ml distilled water and vortexed for 15 s every 5 min. After 40 min, the suspensions were centrifuged at 2100×*g* for 10 min (Nüve NF 200, Turkey). Supernatant was dried in an oven at 100 °C to attain constant weight, and the solubility was calculated as follows;

$$\text{Solubility}\ (\%) = \frac{\text{weight of dried supernatant}}{\text{weight of sample}} \times 100$$

Precipitate was weighed and then dried at 100 °C. WBC was calculated as follows;

$$\text{WBC}\ (\%) = \frac{\text{weight of wet precipitate}}{\text{weight of sample}} \times 100$$

2.5. Cookie production

The cookies were prepared by AACCI Method No: 10–54 (AACCI, 2000). Cross-linked wheat and corn starches were added into the formulation at the levels of 0, 25, 50 and 75% (flour basis). In order to compare the effects of these starches with other commercial RS samples, Hylon VII (RS2), Novelose330 (RS3), Fibersym (RS4) were used in cookie production at the same levels. Wheat bran, native wheat and native corn starches were also used for comparison. Baking was performed in a rotary oven (Simsek Laborteknik, Ankara, Turkey) at 205 ± 2 °C for 11 min. The baked cookies were left to cool for 30 min and then they were wrapped in aluminium foil and allowed to stand at room temperature until analysis.

2.6. Analysis of cookies

The quality parameters of the cookies were evaluated in terms of width (W), thickness (T), spread ratio (W/T), colour (L*, a*, b*) and texture (maximum force to break the cookie) values. After cooling of the cookies for 30 min, width and thickness measurements of the cookie samples were taken by using a calliper. The surface colour values (CIE L*, a*, b*) of cookies were determined by image processing technology with MATLAB (Gökmen and Süğüt, 2007). Texture Analyser (TAPlus, Lloyd Instruments, UK) equipped with a three-point bending jig was used for texture analysis, and the maximum force (Newton) required to break the cookie sample was determined 72 h after baking. The span between the supports was 40 mm. A load cell of 1.000 N was used.

2.7. Determination of total dietary fibre

As stated in our previous study (Kahraman et al., 2015), the method used for the determination of RS content of a sample (AACCI Method No: 32–40, AACCI, 2000) cannot be used for cross-linked starches, as the RS part of these starches could not be dissolved in KOH. Therefore, total dietary fibre (TDF) content of starch samples, wheat bran and cookie samples were determined according to AACCI Method: 32-05.01 (AACCI, 2000). Cookie samples were defatted prior to analysis.

2.8. Estimation of in vitro glycaemic index value

For the estimation of *in vitro* glycaemic index (GI) value of the cookie samples, defatted cookie samples were firstly digested according to the method of Englyst et al. (1992). For this purpose samples (100 mg) were weighed into 50 ml tubes with 10 glass beads (5 mm diameter) added to each tube. Two millilitres of 0.05 M hydrochloric acid (HCl) and 10 mg of pepsin (Sigma, P7000) were added and the tubes were incubated at 37 °C in a shaking water bath for 30 min. Then, 4 ml of sodium acetate buffer (0.5 M, pH 5.2) was added to each tube. One millilitre of freshly prepared enzyme solution containing 0.139 g pancreatin (Sigma-Aldrich, P7545) and 14.26 U amyloglucosidase (3300 U/ml, Megazyme Int., Ireland) was added, and the tubes were incubated vertically at 37°C in a shaking water bath. Invertase (2 mg/ml) was also included in the enzyme solution to convert sucrose, found in the cookie formulation, to glucose and fructose, to simulate the *in vivo* digestion of sucrose. Aliquots (100 µL) were taken at 0, 10, 20, 30, 60, 90, 120, and 180 min intervals and mixed with 1 ml of absolute ethanol. These solutions were centrifuged at 800 g for 10 min, and glucose content of the supernatant was measured with glucose oxidase-peroxidase (GOPOD) reagent (Megazyme Int., Ireland) by using spectrophotometer (Shimadzu 1601, Japan) at 510 nm wavelength. Total starch hydrolysis (%) in the samples was calculated as follows;

$$\text{Total Hydrolysis } (\%) = \left[\frac{\left(\text{Released Glucose Weight} \times \frac{160}{182}\right)}{\text{Total Starch Weight}} \right] \times 100$$

Several researchers showed a high correlation between the rate of starch digestion and the glycaemic response by various *in vitro* digestion methods that imitate the *in vivo* methods (Goni et al., 1997).

Goni et al. (1997) stated that the kinetics of *in vitro* digestion is followed by a nonlinear model with a first order equation of $C = C_\infty(1 - e^{-kt})$, where C is the percentage of starch hydrolysed at time t (min), C_∞ is the equilibrium percentage of starch hydrolysed after 180 min, and k is the kinetic constant. The rate of starch digestion was expressed as the percentage of total starch hydrolysis (%) at different times (30, 60, 90, 120 and 180 min). Total starch hydrolysis (%) values of the samples were plotted against time (min) and the area under the curve was calculated using Microsoft Excel. Hydrolysis index (HI) represents the rate of starch digestion in the samples in relation to the digestibility of starch in a reference material, white bread. The HI was calculated as follows;

$$\text{HI} = \frac{\text{Area under the curve of the sample}}{\text{Area under the curve of reference sample (white bread)}}$$

The *in vitro* GI was calculated by using the equation of Goñi et al. (1997);

$$\textit{in vitro}\ \text{GI} = 39.71 + 0.549 \times \text{HI}$$

2.9. Statistical evaluation

Data were analysed using one-way analysis of variance (ANOVA, SPSS Inc.). When significant ($p < 0.05$) differences were found, DUNCAN test was used to determine the differences among means.

3. Results and discussion

3.1. Flour quality

Ash, protein and wet gluten contents of the flour sample were 0.71%, 9.3% and 24.0% (dry basis), respectively. Sedimentation value was 18 ml and falling number was 305 s. Farinograph water absorption, softening degree, dough development time, and stability values were 57.3%, 90 BU, 1.5 min, and 2.75 min, respectively. Mixolab water absorption and stability value were 53.1% and 2.75 min, respectively. Ideal flour for cookie (biscuit) production should have low protein content with weak and extensible gluten properties (Manley, 1991; Delcour and Hoseney, 2013). The results of the present study indicated that the selected flour sample had low protein content with weak and extensible gluten properties. Hence, overall results indicated that the quality of the flour sample was suitable for cookie production.

3.2. Solubility and water binding properties

Solubility and water binding properties of the starch samples and wheat bran are shown in Table 1. Solubility of wheat bran and a commercial starch, Novelose 330, were 11.89% and 7.13%, respectively. The solubility of native and cross-linked corn (XL-C) and wheat starch (XL-W) samples, and the other commercial starches (Fibersym and Hylon VII) were similar and varied between 0.31% and 0.36%, which were significantly lower than those of the other samples ($p < 0.05$). The solubilities of wheat bran and native corn starch were both lower than those found in the literature (Mishra and Rai, 2006; Ralet et al., 1990). The lower solubility of bran could be related the particle size distribution. It is well known that water binding of fibres decreases with decreasing particle size (Auffret et al., 1994). While, low solubility of starch could be attributed to the semi-crystalline structure of the starch granule and the hydrogen bonds formed between hydroxyl groups in the starch molecules (Mishra and Rai, 2006).

Water binding capacity (WBC) is the amount of water retained by a known weight of fibre/starch under the certain conditions after centrifugation. WBC of wheat bran was the highest as 288.2%. It is also reported in the literature that the wheat bran had the highest WBC in between different starch and fibre sources (Woo et al., 2009). On the contrary, native and cross-linked wheat and corn starches and Fibersym had the lowest WBC (ranging between 100.4 and 107.0%). A commercial starch, Novelose 330, had a higher WBC value (241.5%) than the other commercial starches (Hylon VII and Fibersym). It is reported by Gelencsér (2009) that the lowest WBC value (61.2%) was observed in Fibersym and a higher (191.0%) was in Novelose 330. In addition, the native wheat and maize starches was reported to have WBC around 80.0%, which was lower than those found in present study (Gelencsér, 2009). The degree of availability of the water binding sites to interact with water depending on structure and compositional differences of the starches may have an effect on differences in WBC values (Mishra and Rai, 2006). WBC value of lab-scale produced cross-linked wheat starch (XL-W) was higher than that of reported in the literature (Woo et al., 2009). High WBC of starches could be attributed to the involvement of a less proportion of the hydroxyl groups in forming the hydrogen bonds and covalent bonds between starch chains than with water (Hoover and

Table 1
Solubility and water binding capacity of different resistant starch sources and wheat bran.

Source	Solubility (%)	Water Binding Capacity (%)
Corn starch	0.33 c	102.8 de
Wheat starch	0.36 c	107.0 d
XL-C	0.36 c	101.7 de
XL-W	0.31 c	106.5 d
Hylon VII	0.35 c	146.2 c
Novelose 330	7.13 b	241.5 b
Fibersym	0.34 c	100.4 e
Wheat bran	11.89 a	288.2 a

[a-e] Values in the same column with different superscript letters differ significantly ($p < 0.05$).
XL-C: lab-scale produced cross-linked corn starch, XL-W: lab-scale produced cross-linked wheat starch.

Sosulski, 1986).

3.3. Cookie quality

The native and cross-linked wheat and corn starches and Fibersym had relatively low WBC (ranging between 100.4 and 107.0%). Whereas, Novelose 330 (RS3) and Hylon VII (RS2) had higher WBC values (241.5 and 146.2%). A constant level of water was added during cookie dough preparation according to AACC Method (AACCI, 2000). Therefore, supplementation of cookie flour with RS samples having high WBC resulted in stiffer dough as expected. The manual evaluation of the cookie dough samples indicated that the consistency (stiffness) of cookie doughs supplemented with Novelose 330 and Hylon VII was higher than those supplemented with other starches.

Physical properties (width, thickness and spread ratio values) of cookie samples supplemented with different starches and wheat bran are presented in Table 2. The cookie sample without any supplementation was used as control cookie. The width and the thickness of control cookie was 84.6 and 8.6 mm, respectively. The spread ratio which was calculated by dividing width to thickness was 9.8 for the control cookie. In general, with the increase in addition level, width of the cookie samples decreased while the thickness increased, indicating a deterioration in cookie quality. All decreases and increases were statistically significant with increasing addition level for Novelose 330 and wheat bran supplemented cookie samples ($p < 0.05$). It is also reported in the literature that the supplementation of cookie samples with wheat bran above 10% level significantly decreased the spread ratio of cookies (Sudha et al., 2007). On the other hand, the cookie samples supplemented with 50 and 75% cross-linked wheat starch (XL-W) had an improving effect on cookie quality with significantly ($p < 0.05$) higher width and lower thickness values compared to the control cookie (Table 2). As indicated above supplementation of cookie flour with RS samples (or bran) having high WBC (Table 1) resulted in stiffer dough. Therefore, a higher dough consistency resulted in lower spread ratio in cookies (Table 2). Yeo and Seib (2009) reported that cookie doughs prepared by Hylon VII supplementation had increased dough consistency, as also observed in this study, while cookie dough supplementation of XL-RS4 resulted in a lower consistency. In the present study, Novelose 330 supplementation at 75% level resulted in very tough dough due to its high WBC value (241.5%, Table 1); therefore, it was not possible to produce a cookie at 75% Novelose 330 supplementation level. The changes in spread ratio values of the cookies supplemented with different starch samples and bran were consistent with the changes in width and thickness values. Increasing the addition levels of wheat bran and other starch samples decreased spread ratio values of the cookie samples, except the cross-linked wheat starch (XL-W) which had an increasing effect on spread ratio at 50 and 75% supplementation levels ($p < 0.05$). It is reported in the literature that the addition of Hylon VII decreased the spread ratio of cookie samples as compared to control cookie, while addition cross-linked wheat starch at the levels of 30 and 50% did not statistically change the spread ratio of cookies (Yeo and Seib, 2009).

Table 2
Physical properties of cookies supplemented with different resistant starch sources and wheat bran.

Source	Addition Level (%)	Width (mm)	Thickness (mm)	Spread ratio
Corn starch	0	84.6 a	8.6 d	9.8 a
	25	82.0 b	9.3 c	8.8 b
	50	80.4 b	10.2 b	7.9 c
	75	74.5 c	11.9 a	6.2 d
Wheat starch	0	84.6 a	8.6 c	9.8 a
	25	83.6 ab	9.3 b	9.0 b
	50	85.2 a	9.2 b	9.3 b
	75	82.3 b	10.0 a	8.3 c
XL-C	0	84.6 a	8.6 c	9.8 a
	25	80.6 b	9.5 b	8.4 b
	50	80.0 b	9.6 b	8.3 b
	75	76.3 c	11.1 a	6.9 c
XL-W	0	84.6 b	8.6 a	9.8 b
	25	84.7 b	8.4 ab	9.8 b
	50	88.3 a	8.3 b	10.6 a
	75	89.2 a	8.3 b	10.8 a
Hylon VII	0	84.6 a	8.6 c	9.8 a
	25	74.9 b	10.9 b	6.9 b
	50	70.4 c	11.8 a	6.0 c
	75	–	–	–
Novelose 330	0	84.6 a	8.6 c	9.8 a
	25	73.3 b	11.5 b	6.4 b
	50	66.2 c	12.7 a	5.2 c
	75	–	–	–
Fibersym	0	84.6 a	8.6 c	9.8 a
	25	83.9 a	8.8 c	9.5 a
	50	83.0 a	9.6 b	8.6 b
	75	80.5 b	10.1 a	7.9 c
Wheat bran	0	84.6 a	8.6 d	9.8 a
	25	73.6 b	12.3 c	6.0 b
	50	68.0 c	13.1 b	5.2 c
	75	64.6 d	14.2 a	4.6 d

[a-d] Values in the same column with different superscript letters differ significantly ($p < 0.05$).
XL-C: lab-scale produced cross-linked corn starch, XL-W: lab-scale produced cross-linked wheat starch.

Moiraghi et al. (2013) reported that the flours that produce high quality cookies hold water poorly; and if the flour holds less water, more water is available for the sugar to form syrup. Therefore, dough viscosity decreases during baking and the dough spreads more, resulting in larger diameter cookies. As indicated above, the WBC values of the cross-linked starches (XL-C, XL-W and Fibersym) were relatively low and a constant level of water was added during cookie dough preparation according to AACC Method (AACCI, 2000). Therefore, supplementation of cookie flour with cross-linked starch samples having lower WBC (Table 1) is expected to result in softer dough and a cookie with greater spread ratio. All of the cross-linked starch samples resulted in better cookie quality characteristics especially up to 50% supplementation level. Hence, WBC seems to be the most important RS property that might influence cookie quality parameters (spread ratio).

Hardness and colour values of the cookie samples supplemented with different starches and wheat bran are presented in Table 3. The hardness value, which is related to the force necessary to break the cookie was 22.9 N for the control cookie, and the supplementation of cross-linked wheat starch and Fibersym at 75% level decreased the hardness values of cookie samples significantly ($p < 0.05$). The native corn starch, Novelose 330 and wheat bran supplementation increased the hardness of the cookie samples compared to the control cookie. It is reported in the literature that RS supplementation did not affect the hardness of the cookie samples at 10% level, while above this up to 40% supplementation level significantly increased the hardness. It is also reported that breaking strength of biscuits increased with addition of wheat bran and RS (Özboy-Özbaş et al., 2010; Sudha et al., 2007). Novelose 330 is a commercial modified starch produced by retrogradation of corn starch that can be considered as RS3. Supplementation of native wheat starch and cross-linked corn starch did not significantly affect the hardness of the samples. The present study has confirmed that cross-linked corn starch eliminates the negative effects of native and retrograded corn starches on hardness of cookies.

The L*, a* and b* values of control cookie were 76.2, 8.7 and 39.5, respectively (Table 3). Starch supplementation increased L* values and decreased a* and b* values of the cookie samples. This is probably due to the decelerated Maillard reactions because of the replacing flour with starches resulting in decreased protein in the cookie dough. The most obvious changes in colour (significant increases in L* values, and significant decreases in a* and b* values) were observed in the cookies supplemented with Hylon VII after all addition levels. The L* value of the cookie sample supplemented with Hylon VII at 50% level increased to 86.4, while a* and b* values decreased to 1.7 and 23.7, respectively.

Table 3
Texture and colour values of cookies supplemented with different resistant starch sources and wheat bran.

Source	Addition Level (%)	Hardness (N)	L*	a*	b*
Corn starch	0	22.9 b	76.2 c	8.7 a	39.5 a
	25	25.0 b	79.3 bc	8.2 a	32.9 b
	50	33.9 a	80.8 b	4.7 b	26.8 c
	75	35.3 a	84.4 a	3.0 c	24.9 c
Wheat starch	0	22.9 a	76.2 c	8.7 a	39.5 a
	25	23.5 a	78.3 bc	7.3 b	32.8 b
	50	22.4 a	80.0 b	6.9 b	33.2 b
	75	24.4 a	82.6 a	4.8 c	28.6 c
XL-C	0	22.9 a	76.2 c	8.7 a	39.5 a
	25	24.1 a	79.0 b	8.2 a	32.6 b
	50	23.5 a	82.4 a	5.9 b	29.9 c
	75	21.9 a	83.4 a	4.0 c	26.6 d
XL-W	0	22.9 a	76.2 c	8.7 a	39.5 a
	25	21.5 a	80.3 b	6.3 b	33.1 b
	50	20.1 a	80.7 b	5.7 b	31.0 bc
	75	16.1 b	84.9 a	4.3 c	29.2 c
Hylon VII	0	22.9 a	76.2 d	8.7 a	39.5 a
	25	24.8 a	83.0 c	5.0 b	29.1 b
	50	19.4 a	86.4 b	1.7 c	23.7 c
	75	–	–	–	–
Novelose 330	0	22.9 b	76.2 c	8.7 a	39.5 a
	25	33.8 a	83.5 b	5.6 b	31.2 b
	50	30.5 a	86.6 a	3.4 c	26.1 c
	75	–	–	–	–
Fibersym	0	22.9 a	76.2 d	8.7 a	39.5 a
	25	23.1 a	80.7 c	5.9 b	34.5 b
	50	19.8 b	83.7 b	4.4 c	32.1 c
	75	17.6 b	87.9 a	2.6 d	26.5 d
Wheat bran	0	22.9 c	76.2 a	8.7 b	39.5 a
	25	53.3 b	68.3 b	8.9 b	31.1 b
	50	81.3 a	65.5 c	9.1 a	30.3 b
	75	88.3 a	61.7 d	9.3 a	31.3 b

[a-d] Values in the same column with different superscript letters differ significantly ($p < 0.05$) for each resistant starch source and wheat bran.
XL-C: lab-scale produced cross-linked corn starch, XL-W: lab-scale produced cross-linked wheat starch.

Similar findings were also observed by Özboy-Özbaş et al. (2010) for the cookie samples supplemented with RS at different levels. On the other hand, the wheat bran supplementation had an inverse effect on L* and a* values of cookie samples as also reported by Sudha et al. (2007).

3.4. Total dietary fibre content

Total dietary fibre (TDF) contents of native corn, native wheat, cross-linked corn (XL-C), cross-linked wheat (XL-W) starches, Hylon VII, Novelose 330, Fibersym and wheat bran were determined as 2.5%, 3.0%, 80.1%, 82.7%, 16.1%, 36.5%, 69.9% and 48.5%, respectively. The TDF values of cross-linked corn starch and Hylon VII were comparable with the literature. Yeo and Seib (2009) reported that the TDF content of cross-linked corn starch and Hylon VII were 79.5% and 14.3%, respectively.

TDF contents of the cookie samples supplemented with different starches and wheat bran are presented in Table 4. TDF contents of the cookie samples supplemented with native corn and wheat starches were quite low, and the increase in addition level did not result in significant difference, as expected. The highest TDF content (32.4%) was obtained at the cookie sample supplemented with cross-linked wheat starch at 75% level. Although TDF contents of cross-linked wheat (82.7%) and cross-linked corn (80.1%) starches were comparable, TDF content of cookie sample supplemented with cross-linked wheat starch was higher at the same addition levels. It can be due to more stable structure of cross-linked wheat starch than cross-linked corn starch in processing conditions of cookie production. High levels of TDF (18.0 and 27.2%) was observed when the wheat bran supplemented at 50 and 75% levels; however, physical and colour quality of bran supplemented cookies were low and may not be accepted by consumers, especially at higher supplementation levels. Among the cookie samples supplemented with different RS sources, the one supplemented with the cross-linked wheat starch sample produced in this study had the highest TDF content regardless of the addition level.

Table 4
Total dietary fibre contents of cookies supplemented with different resistant starch sources and wheat bran.

Source	Addition Level (%)			
	0	25	50	75
Corn starch	1.0 a	1.2 a	1.1 a	1.1 a
Wheat starch	1.0 a	1.3 a	1.4 a	1.2 a
XL-C	1.0 d	5.2 c	10.4 b	18.0 a
XL-W	1.0 d	16.0 c	22.7 b	32.4 a
Hylon VII	1.0 b	1.5 b	3.8 a	–
Novelose 330	1.0 d	7.4 c	10.4 b	–
Fibersym	1.0 d	10.7 c	19.4 b	25.1 a
Wheat bran	1.0 d	12.4 c	18.0 b	27.2 a

[a-d] Values in the same row with different superscript letters differ significantly ($p < 0.05$).
XL-C: lab-scale produced cross-linked corn starch, XL-W: lab-scale produced cross-linked wheat starch.

Similar findings were also observed in the studies investigating the effect of RS/bran addition on the TDF content of the cookie samples. Yeo and Seib (2009) and Özboy-Özbaş et al. (2010) also reported that increase in RS level increased TDF content of cookies significantly ($p < 0.05$). Sudha et al. (2007) also reported that wheat bran addition at 20% level significantly ($p < 0.05$) increased TDF content of biscuit samples from 1.6 to 6.9%. While the reported values by Yeo and Seib (2009) for the control cookie and the cookies supplemented with Hylon VII were similar to our study, TDF content of the cookies supplemented with cross-linked wheat starch at 50% level were lower (1.5%) compared to the finding of our study (22.7%).

3.5. In vitro (estimated) glycaemic index value

The *in vitro* glycaemic index (GI) values were determined only in the cookie samples supplemented with 50% of RS sources and wheat bran. GI values are presented in Table 5. White bread was used as reference food and its GI was assumed as 100. The GI of foods depends on the raw material, food processing, ingredients, grain/fibre/RS addition, etc. (Ferrer-Mairal et al., 2012). In general, due to their richness in sugar and white flour, cookie products belong to high GI categories. The increase in RS or fibre content is expected to lead a decrease in the GI of the food. As the native corn and wheat starch samples had very low RS content,

Table 5
In vitro glycaemic index (GI) values of cookies supplemented with different resistant starch sources and wheat bran.

Source	*In vitro* GI[a]
Control cookie	112.1 a
Corn starch	111.2 a
Wheat starch	110.5 a
XL-C	78.8 e
XL-W	77.2 e
Hylon VII	83.0 d
Novelose 330	86.2 c
Fibersym	81.7 d
Wheat bran	88.1 b

[a-e] Values in the same column with different superscript letters differ significantly ($p < 0.05$).
XL-C: lab-scale produced cross-linked corn starch, XL-W: lab-scale produced cross-linked wheat starch.
[a] *In vitro* GI values were determined only in the cookie samples supplemented with 50% level.

the GI value of the cookie samples were similar to those of control sample as expected. The GI of control cookie was 112.1 (the highest), and there was no significant difference between the GI of control cookie and those of the cookie samples supplemented with native corn (GI: 111.2) and wheat (GI:110.5) starches. However, the addition of different RS sources to the cookie formulation caused significant decreases in the GI values of the cookie samples. GI of the cookie samples supplemented with commercial RS sources, Fibersym, Hylon VII and Novelose 330, was 81.7, 83.0 and 86.2, respectively. The cookie samples supplemented with lab-scale produced cross-linked wheat and corn starches had the lowest GI values (77.2 and 78.8, respectively).

As stated above, TDF contents of lab-scale produced cross-linked corn (80.4%) and wheat (83.6%) starch samples were higher than the commercial RS sources (Hylon VII; Novelose 330, Fibersym). The lower GI value of the cookie samples supplemented with lab-scale produced cross-linked wheat and corn starch samples compared to the ones supplemented with commercial RS sources could be attributed to the high TDF content of the RS sources. There are some studies investigating the effect of RS addition on the GI values of the bakery products and similar finding were also observed. Agama-Acevedo et al. (2012) reported that the estimated GI value of control cookie (116.8) decreased down to 98.6 with increasing level of unripe banana flour which contains RS2 as a fibre source. Aparicio-Saguilán et al. (2007) and Reyes-Pérez et al. (2013) reported lower GI value of control cookie (77.62 and 80.16, respectively), and estimated GI value decreased to 60.0 with the addition of RS-rich powder (Aparicio-Saguilán et al., 2007), and around 73.0 with the addition of wheat bran (Reyes-Pérez et al., 2013). Srikaeo and Sangkhiaw (2014) also reported that the estimated GI of noodles decreased from 99.0 to 71.7 after supplementation of high amylose maize starch at 50% level. Moreover, relatively low GI value (64.3) was also observed for the bread produced with unripe banana flour (Juarez-Garcia et al., 2006).

4. Conclusions

The findings of this study showed that the cross-linked wheat starch sample produced in lab-scale had an improving effect on cookie quality whereas the other RS/fibre sources had opposite effect. The TDF content of the cookie samples could be maximised at a 50% addition level with acceptable cookie quality. In general, due to their richness in sugar and white flour, bakery products such as cookies belong to medium-to-high GI categories. Reducing the GI is of particular interest in commonly consumed cereal products. The cookie samples produced using cross-linked starches (both lab-scale and commercial RS4), Hylon VII, Novelose 330 and wheat bran had lower GI than the control sample. The lowest GI value was achieve with the addition of the cross-linked RS4 samples produced in this study (XL-C and XL-W). Among the cookie samples the highest TDF content was determined in the one supplemented with the XL-W. Overall results indicate that the cross-linked wheat starch produced in this study (XL-W) can be an alternative ingredient in low GI and high fibre cookies without any deteriorative effect that is usually caused by wheat bran incorporation.

Declaration of competing interest

The authors have no conflict of interest regarding the content of this paper.

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References

AACC International, 2000. Approved Methods of Analysis, tenth ed. AACC International, St. Paul, 4 MN, U.S.A.
Agama-Acevedo, E., Islas-Hernández, J.J., Pacheco-Vargas, G., Osorio-Díaz, P., Bello-Pérez, L.A., 2012. Starch digestibility and glycemic index of cookies partially substituted with unripe banana flour. LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 46 (1), 177–182.
Aparicio-Saguilán, A., Sáyago-Ayerdi, S.G., Vargas-Torres, A., Tovar, J., Ascencio-Otero, T.E., Bello-Pérez, L.A., 2007. Slowly digestible cookies prepared from resistant starch-rich lintnerized banana starch. J. Food Compos. Anal. 20, 175–181.
Ashwar, B.A., Gani, A., Shah, A., Wani, I.A., Masoodi, F.A., 2016. Preparation, health benefits and applications of resistant starch - a review. Starch Staerke 68, 287–301.
Auffret, A., Ralet, M.C., Guillon, F., Barry, J.L., Thibault, J.F., 1994. Effect of grinding and experimental conditions on the measurement of hydration properties of dietary fibres. LWT (Lebensm.-Wiss. & Technol.) 27 (2), 166–172.
Birt, D.F., Boylston, T., Hendrich, S., Jane, J.-L., Hollis, J., Li, L., McClelland, J., Moore, S., Phillips, G.J., Rowling, M., Schalinske, K., Scott, M.P., Whitley, E.M., 2013. Resistant starch: promise for improving human health. Adv. Nutr.: Int. Rev. J. 4, 587–601.
Delcour, J., Hoseney, R.C., 2013. Principles of Cereal Science and Technology. American Association of Cereal Chemists, USA.
Devi, A., Khatkar, B.S., 2016. Physicochemical, rheological and functional properties of fats and oils in relation to cookie quality: a review. J. Food Sci. Technol. 53 (10), 3633–3641.
Englyst, K.N., Kingman, S.M., Cummings, J.H., 1992. Classification and measurement of nutritionally important starch fractions. Eur. J. Clin. Nutr. 46, 33–50.
Ferrer-Mairal, A., Peñalva-Lapuente, C., Iglesia, I., Urtasun, L., De Miguel-Etayo, P., Remón, S., Cortés, E., Moreno, L.A., 2012. In vitro and in vivo assessment of the glycemic index of bakery products: influence of the reformulation of ingredients. Eur. J. Nutr. 51 (8), 947.
Fuentes-Zaragoza, E., Riquelme-Navarrete, M.J., Sánchez-Zapata, E., Pérez-Álvarez, J.A., 2010. Resistant starch as functional ingredient: a review. Food Res. Int. 43, 931–942.
Gelencsér, T., 2009. Comparative Study of Resistant Starches and Investigations of Their Application in Starch-Based Products (Bread and Pasta). Ph.D. Thesis. Budapest University of Technology and Economics, Budapest, Hungary.
Goñi, I., Garcia-Alonso, A., Saura-Calixto, F., 1997. A starch hydrolysis procedure to estimate glycemic index. Nutr. Res. 17 (3), 427–437.
Gökmen, V., Süğüt, I., 2007. A non-contact computer vision based analysis of color in foods. Int. J. Food Eng. 3 (5). Article 5.
Haralampu, S.G., 2000. Resistant starch - a review of the physical properties and biological impact of RS_3. Carbohydr. Polym. 41, 285–292.
Hoover, R., Sosulski, F., 1986. Effect of cross-linking on functional properties of legume starches. Starch - Stärke 38, 149–155.
Juarez-Garcia, E., Agama-Acevedo, E., Sáyago-Ayerdi, S.G., Rodríguez-Ambriz, S.L., Bello-Pérez, L.A., 2006. Composition, digestibility and application in breadmaking of banana flour. Plant Foods Hum. Nutr. 61, 131–137.
Kahraman, K., Koksel, H., Ng, P.K.W., 2015. Optimisation of the reaction conditions for the production of cross-linked starch with high resistant starch content. Food Chem. 174, 173–179.
Maningat, C., Bassi, S., Woo, K., Dohl, C., Gaul, J., Stempien, G., 2005. Formulation of high-protein, high-fiber (Low-Carbohydrate), reduced calorie breads. Low-Carbohydr. Bread Tech. Bull. 27 (4), 1–16.
Manley, D.J.R., 1991. Manley's Technology of Biscuits, Crackers and Cookies. Woodhead Publishing, Cambridge.
Mishra, S., Rai, T., 2006. Morphology and functional properties of corn, potato and tapioca starches. Food Hydrocolloids 20, 557–566.
Moiraghi, M., Vanzetti, L., Pflüger, L., Helguera, M., Pérez, G.T., 2013. Effect of high molecular weight glutenins and rye translocations on soft wheat flour cookie quality. J. Cereal Sci. 58, 424–430.
Özboy-Özbaş, Ö., Seker, I.T., Gökbulut, I., 2010. Effects of resistant starch, apricot kernel flour, and fiber-rich fruit powders on low-fat cookie quality. J. Food Sci. Biotechnol. 19 (4), 979–986.
Ozturk, S., Koksel, H., Kahraman, K., Ng, P.K.W., 2009. Effect of debranching and heat treatments on formation and functional properties of resistant starch from high-amylose corn starch. Eur. Food Res. Technol. 229 (1), 115–125.
Ralet, M.-C., Thibault, J.-F., Della Valle, G., 1990. Influence of extrusion-cooking on the physico-chemical properties of wheat bran. J. Cereal Sci. 11, 249–259.
Reyes-Pérez, F., Salazar-García, M.G., Romero-Baranzini, A.L., Islas-Rubio, A.R., Ramírez-Wong, B., 2013. Estimated glycemic index and dietary fiber content of cookies elaborated with extruded wheat bran. Plant Foods Hum. Nutr. 68, 52–56.
Srikaeo, K., Sangkhiaw, J., 2014. Effects of amylose and resistant starch on glycaemic index of rice noodles. LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 59, 1129–1135.
Sudha, M.L., Vetrimani, R., Leelavathi, K., 2007. Influence of fibre from different cereals on the rheological characteristics of wheat flour dough and on biscuit quality. Food Chem. 100, 1365–1370.
Woo, K.S., Maningat, C.C., Seib, P.A., 2009. Increasing dietary fiber in foods: the case for phosphorylated cross-linked resistant starch, a highly concentrated form of dietary fiber. Cereal Foods World 54 (5), 217–223.
Yeo, L.L., Seib, P.A., 2009. White pan bread and sugar-snap cookies containing wheat starch phosphate, a cross-linked resistant starch. Cereal Chem. 86 (2), 210–220.