Sensory, rheological and chemical characteristics during storage of set type full fat yoghurt fortified with barley β -glucan

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Revised: 23 June 2019 / Accepted: 12 August 2019 / Published online: 28 August 2019
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Abstract β -Glucan, is a soluble dietary fiber and is obtained from number of sources including cereals. It possesses the nutraceutical characteristics and acts as functional bioactive ingredient in the fermented dairy product including yoghurt. In this concern, β -glucan isolated from barley having purity of (91.52%) was incorporated in different proportions (0.5, 1, 1.5 and 2%, w/v) during the full fat yoghurt preparation. The analysis of β -glucan carried out initially, indicated that the viscosity, water binding capacity, swelling power and solubility values were 92 Pa s, 3.17 g/g, 18.50 g/g and 3%, respectively, whereas, the total antioxidant activity obtained in terms of DPPH free radical scavenging activity was 27%. Based on these characteristics β -glucan extract had been considered as the choicest material for set type products like yoghurt. Thereafter, physiochemical, rheological and sensory characteristics of β -glucan incorporated yoghurt were evaluated during 1st, 7th and 14th days of refrigerated storage. Addition of β -glucan significantly ($p \leq 0.05$) improved whey separation (syneresis), viscosity, texture profile and sensory characteristics during storage. The TPA characteristics such as hardness, cohesiveness and resilience of yoghurt samples improved significantly during storage with the incorporation of β -glucan whereas, β -glucan added yoghurt obtained higher consistency

coefficient (K), thus, indicated a thicker and compact texture. Sensory analysis of stored yoghurt indicated that yoghurt samples in the present study containing even higher (1.5–2%) β -glucan level had obtained the higher average overall acceptability (8.1 to 8.3 on 9-point scale) score as compared to a low fat yoghurt containing lower β -glucan level (0.5%) reported in the literature.

Keywords Yoghurt · β -Glucan · Texture profile analysis · Sensory analysis · Storage · Antioxidant activity

Introduction

Soluble dietary fiber from the cereal sources has received tremendous attention during the previous decades because of its great effect on the maintenance and improvement of human health. Dietary fiber is classified into two categories such as soluble and insoluble (Grausgruber et al. 2004). Effects of dietary fiber on human health are diverse and extremely advantageous. It helps in reducing the occurrence of various chronic diseases such as high blood pressure, insulin responses, obesity and colon cancer (Khouri et al. 2012).

Cereals such as oat and barley contain β -glucan in an appreciable amount and are considered as the major sources of soluble dietary fiber along with bioactive components (Guleria et al. 2015). β -Glucan is a non-starchy polysaccharides comprises mainly of glucose molecules linked by (1–3), (1–4) mixed linkage with glycosidic bonds. In oats and barley, glucose monomers are linked via β -(1 $\rightarrow$ 4) and β -(1 $\rightarrow$ 3) glycosidic bonds. β -Glucan is commercially derived from oats, barley, mushrooms and some microorganisms. In microorganisms and mushrooms, these compounds are found to have a linear chain of D-

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-019-04027-7>) contains supplementary material, which is available to authorized users.

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glucose linked in the β (1–3) position with various sized D-glucose branches linked to the main chain by β (1–6) linkages. β -Glucan derived from cereals are polymers of D-glucose with β , (1–3) and β , (1–4) linkages. β -Glucan constitutes 1% of wheat grains, 3–7% of oats and 5–11% of barley (Guleria et al. 2015). Positive health benefits of β -glucan include, enhancing the host immune defense, act as a very powerful antagonist to both types of tumours (benign and malignant tumors), reduces blood cholesterol and post-prandial glucose levels. It also rejuvenates the skin, has insulin responses and various other benefits (Khoury et al. 2012; Inglett et al. 2015).

Over the years, there is growing interest to launch new functional foodstuffs such as cookies, soups, breads and dairy food products with added soluble dietary fiber β -glucan for potential health benefits. Fermented dairy products constitute a vital component of the human diet globally (Aboushanab et al. 2018). Yoghurt, a lactic acid fermentation milk product is popular among people of most countries regardless of their human development index. Yoghurt enjoys a positive reputation in the minds of consumers for being considered as a healthy product (Annunziata and Vecchio 2013). Mudgil et al. (2016) used hydrolyzed guar gum as a soluble dietary fiber source in yoghurt and found that addition of soluble fiber enhances the functional and sensory properties. Since, the milk and milk products lack dietary fiber, β -glucan is an appropriate option for dairy systems. It also helps in improving nutritional and rheological properties of the product. The β -glucan has the power to increase viscosity and gel forming capacity in aqueous systems. These characteristics are beneficially linked to the rheological characteristics of milk products such as low fat ice creams and yoghurt (Batista et al. 2015). Consumers preference for new products are variable and each comparative methodology based on sensory profiling techniques (CATA, Projective Mapping and Pivot Profile methods etc.) used for evaluation has shown variable responses with no methodology has been reported to have adequate preference (Esmerino et al. 2017), however, sensory methodologies using consumer responses used in present study presents potential options for the characterization of food matrices with multiple sensory sensations, such as probiotic yoghurt and studies needs to be carried out for comparison of the results obtained from a trained panel using descriptive quantitative analysis (Cruz et al. 2013b).

Studying the characteristics of β -glucan added low fat dahi, it has been reported by Bhaskar et al. (2017) that up to 0.5% addition of soluble fibers gives the best results. Since soluble dietary fiber are important in enhancing the nutraceutical quality and physical characteristics of food, various researchers used β -glucan along with guar gum and inulin added in low fat milk to show its effect either on

starter culture growth and various physicochemical and rheological characteristics (Gee et al. 2007; Vanegas-Azuero and Gutiérrez 2018). Recently, Aboushanab et al. (2018) reported that addition of different concentrations of β -glucan impart significant affect on sensory evaluation results, syneresis problem, and on water holding capacity. However, its impact on yoghurt quality during storage has been a concern of research. Therefore, in the present study, β -glucan extracted from barley was incorporated in different proportion during yoghurt preparation in order to determine assertion on its possible beneficial effect on physicochemical, rheological and sensory properties of yoghurt during storage.

Materials and methods

Materials

Barley (*Hordeum vulgare* L.) variety, Ranjit DL-70, was obtained from local market of Sangur, Punjab. Pasteurized and standardized milk (4.5% fat) under the brand name “Verka”, manufactured by milk producer’s Union Ltd. (Sangrur) was procured from local market. The mixed culture for yoghurt containing *Lactobacillus bulgaricus* and *Streptococcus thermophilus* was procured from National Dairy Research Institute, Haryana, India and was reactivated in the laboratory as per the standard procedure provided by the supplier used for reactivation of freeze dried lactic culture before use. The required chemicals for experimental investigation were of analytical grade and were obtained from Sigma Aldrich, India, Ltd.

Methods

Preparation of raw material

Whole grains of barley were pulverized to fine flour with a hammer mill (Indosa, Pvt. Ltd, India) (Hammer mill is an ideal mill and preferred over other mill for grinding of coarse cereals grain like barley etc.). The resultant flour was sieved through 60 mesh sieve and stored at 4 °C in air tight food grade container until used. Barley flour was initially analyzed for moisture, protein, fat and ash content by AACC (2003) methods.

Extraction and analysis of β -glucan

The standard procedure for extraction of β -glucan from barley as reported by Vizhi and Many (2012) was used (Fig. 1S). The yield of crude β -glucan extract was calculated on 100 g barley flour basis. The β -glucan content was estimated on dry weight basis using β -glucan enzymatic

assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland). Chemical composition like protein, fat and ash content of the β -glucan extract were determined by the method of AACC (2003). Functional properties like swelling power (SP) and solubility (SOL) were determined by the method of Babic et al. (2009). Water binding capacity (WBC) of β -glucan was determined according to the modified method of Wong et al. (2005). Foaming capacity (whippability) of β -glucan was determined by the method of Ahmad et al. (2009). The dynamic rheological properties of β -glucan was measured by Paar Physica MCR 300 Rheometer (Gaz, Austria), equipped with a parallel plate measuring geometry. Plate diameter was set as 30 mm and the gap between the plates was maintained at 1 mm. Viscosity of 1% (w/v, basis) dispersion of β -glucan in water was measured from the obtained curve of shear stress/shear rate of β -glucan, whereas, effect of temperature on the β -glucan viscosity was also studied (Singh and Kaur 2017). The method of Brand-Williams et al. (1995) was followed for determination of antioxidant activity. Sample in triplicate were taken for analysis.

Preparation of control and β -glucan added yoghurt

Yoghurt samples (1000 g each) containing β -glucan in different proportions (0, 0.5, 1, 1.5 and 2%, w/v, on milk basis) were prepared and designated as control, YBG₁, YBG₂, YBG₃ and YBG₄, respectively. Initially, starter culture consisting of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* having cellular concentration of 10^8 cells/g (measured by total viable count, standard plate count, anaerobically inoculated at 37 ± 1 °C for 48 h) was used for inoculation. Preparation of fortified yoghurt started with homogenization of milk containing 4.5% fat with 2% skim milk powder (skim milk powder was added to the yoghurt to enhance the total solids content and consistency of the final product (Lucey 2002), followed by heating for 5 min. β -Glucan as per formulation was dispersed separately into 100 ml of warm milk at 60 °C with continuous stirring for 10 min and then introduced into rest of the milk used for yoghurt preparation, and stirred for 2 min. To the resultant milk, sugar (12%) was added, mixed for 5 min and then pasteurized at 80 °C for 5 min. After cooling to 45 °C, the mixture was seeded with lactic culture (0.02%, v/v) (*Streptococcus thermophilus* and *Lactobacillus delbrueckii*). After incubation at 45 °C for 4 h, the prepared yoghurts samples (1000 g) were cooled and stored in a refrigerator at 4 ± 2 °C. Physiochemical and rheological properties (200 ml) of the samples were evaluated in triplicates during 1st, 7th and 14th days of storage.

Characterization of prepared yoghurt

Acidity and pH

Acidity of control and β -glucan added yoghurt samples were calculated according to the method of Nikoofar et al. (2013), whereas, pH was measured using a digital pH meter. Readings were recorded during first day and after 1 week interval for yoghurt samples containing different concentrations of β -glucan.

Rheological characteristics

Texture profile analysis (TPA) The TPA was performed for intact stored yoghurt samples (tests samples were taken out of refrigerator (4 °C) just before test operation) using a texture profile analyzer (TAXT2 plus) as per instrument protocol. A probe with back extrusion cell containing 35 mm disc and extension bar having 5 kg load cell was used for the purpose. Test speed, post test speed and distance were, 1.0 mm/s, 10.0 mm/s and 30 mm, respectively, as described by Nikoofar et al. (2013). The diameter of beaker for holding the sample was large enough to minimize the probe side wall effects. Yoghurt samples were evaluated in triplicate, for hardness, adhesiveness, cohesiveness, springiness, gumminess, chewiness and resilience.

Viscosity measurements The viscosity of the yoghurt samples was measured at 4 ± 1 °C with spindle (No. 3) of viscometer (DV-II + Pro, Brookfield) rotating at different speed from 10 to 60 rpm. The spindle readings were recorded for yoghurt samples during the first day and after 1 week of storage interval. The power law equation was used to describe the rheological behavior of the yoghurts over different shear rate as:

$$\sigma = k(\dot{\gamma}^n)$$

where σ is the shear stress (Pa), k is the consistency coefficient (Pa s), $\dot{\gamma}$ is the shear rate (1/s), and n is the flow behavior index (dimensionless).

Syneresis measurement For the syneresis measurement, a 25 g sample of yoghurt was taken in a tube and then centrifuged at $500 \times g$ for 5 min (Panesar and Shinde 2011). The volume of supernatant recorded as % syneresis was calculated as:

$$\text{Syneresis (\%)} = \frac{\text{Volume of supernatant}}{\text{Weight of sample}} \times 100$$

Sensory evaluation of yoghurt samples

The sensory analysis of yoghurt samples was carried out using a 9-point Hedonic ranking scale. The sensory panel involved 30-semi-trained panelists (having knowledge of sensory attributes and ability to access and rate the sensory parameters), aged between 20 and 60 years, including staff members, graduate and under graduates students (50% male and 50% female) of the Department of Food Engineering and Technology, SLIET, Longowal. The panel members were selected and trained following the procedure of Meilgard et al. (1999). The samples were taken out from the refrigerator and put into bowls just before the evaluation (Cruz et al. 2013a, b; Hamad and El-Nemr 2015). The tests were carried out in a controlled environment (temperature, 23 °C) and 25 ml of the yoghurt was served at a temperature of 5 °C using plastic cups codified suitably. The panelists were instructed to evaluate the yoghurt samples with respect to the degree of their liking using a nine point Hedonic scale from (1 = Disliked extremely, to 9 = Liked extremely), sequentially on different days indicating that each panel member tested five yoghurt samples in one stretch in two occasion with each yoghurt sample prepared in duplicate. The values obtained for each sensory perception indicates the average of number of panelists values in duplicate for each sample. The members were guided to drink water between samples testing to wash the palate. The samples were rated on the basis of the parameters of physical appearance, mouth feel characteristics, kinesthetic (hardness, cohesiveness, and adhesiveness), taste, color and overall acceptability.

Statistical analyses

The data presented in the tables represent the average of three observations, ($\pm$ SD) and subjected to two way analysis of variance (ANOVA) were applicable followed by Duncan's multiple range test using statistical 7-(statistical $\leq$ soft, TUSA, USA) statistical software packages to determine, significant ($p \leq 0.05$) difference in means.

Results and discussions

Chemical analysis of barley flour and β -glucan

The chemical composition and physicochemical characteristics of barley flour and that of β -glucan extract are shown in Table 1. Barley flour contained moisture (9.6%), protein (10.24%), crude fat (2.4%), ash (0.97%) and carbohydrates (71.89%). Yield of the β -glucan (4.9%) obtained in the present study represented the weight of β -glucan obtained from 100 g of barley flour. Similar

Table 1 Physicochemical and functional characteristics of barley flour and β -glucan

Characteristics (%)	Whole barley flour	Beta glucan
Moisture	9.60 $\pm$ 0.45	3.33 $\pm$ 0.12
Ash	0.97 $\pm$ 0.00	2.25 $\pm$ 0.10
Fat	2.40 $\pm$ 0.11	1.40 $\pm$ 0.01
Protein	10.24 $\pm$ 0.55	2.50 $\pm$ 0.05
Total carbohydrates	71.89 $\pm$ 0.85	ND
Beta glucan	4.90 $\pm$ 0.15	90.52 $\pm$ 0.45
WBC (g/g)	ND	3.17 $\pm$ 0.08
Swelling power (g/g)	ND	18.50 $\pm$ 0.09
Solubility	ND	3.0 $\pm$ 0.02
Foaming capacity	ND	5.0 $\pm$ 0.04
DPPH activity	ND	27.0 $\pm$ 0.2

ND not determined

observations were recorded by Ahmad et al. (2010), who extracted β -glucan from oats by different extraction procedures and noted that yield of β -glucan ranged between 3.74 and 5.14%. Among the constituents of β -glucan extract, total dietary fiber (β -glucan) content obtained was 91.52%, protein (2.5%), ash content (2.25%) and moisture content 3.33%.

The hydration (water binding/holding) properties of β -glucan are essential for many food uses and have an impact on shelf life of food product since it reduce weeping on the surface which prevent texture loss, syneresis and microbial growth. In the present study, water binding capacity, SP and SOL values of β -glucan extract obtained were 3.17 g/g, 18.50 g/g and 3%, respectively (Table 1). These values were in consistent to the results of Subaric et al. (2011). Measurement of WHC and STS is the most common method for estimating the syneresis of fermented milks (Vanegas-Azuero and Gutiérrez 2018). Recently, Aboushanab et al. (2018). The desired value of WBC of β -glucan as obtained in consistent to literature reference values could be used successfully as a functional ingredient to avoid syneresis problem in various food products. The swelling power of β -glucan has been reported to have depends on the water holding capacity of molecules as indicated by their molecular hydrogen binding abilities (Lee and Osman 1991). These functional properties have been considered important when β -glucan is used as a functional ingredient and stabilizer in cake batters, where often a high foaming capacity and stability is desirable. The total antioxidant activity of β -glucan obtained in terms of DPPH free radical scavenging activity was 27% and is considered as having excellent antioxidant activity (Kofuji et al. 2012). Free radical scavenging activities of yeast β -glucan has been documented to be partly responsible for its

immune modulating properties (Kogan et al. 2005). For the reason, it is often recommended to use β -glucan mixed in fruit juices and beverages.

The data for viscosity of β -glucan determined at 20 °C are presented in Fig. 1a, b. The shear stress versus shear rate curve indicated a *pseudo-plastic* behavior of β -glucan samples. In the current study, the effect of temperature on the β -glucan viscosity has also been evaluated. The values

indicated that a viscosity of 92.5 Pa s was attained at initial temperature of 5 °C which was reduced to 0.15 Pa s at final temperature of 80 °C. Similar tests performed by Brennan and Cleary (2005) reported that temperature and pH of solution has profound effect on the viscosity of β -glucan extracts. High viscosity of extracted β -glucan makes it a choicest alternative as thickening agent in different food applications, e.g. ice creams, batter based products (Guleria et al. 2015).

Characterization of prepared full fat yoghurt samples

Yoghurt was prepared by adding different concentrations of β -glucan (0.5, 1, 1.5 and 2%). The prepared yoghurt was conditioned at 4 ± 2 °C prior to its analyses for physico-chemical characteristics and shelf life study parameters such as acidity, pH, syneresis, sensory etc. All the analyses were carried out in triplicate.

Effect of β glucan addition on yoghurt titrable acidity

The trends of acidity measurements of yoghurt samples are shown in Fig. 2a. The acidity of milk (premix) for yoghurt preparation was $0.30 \pm 0.02\%$ in terms of lactic acid. The results showed that acidity value of yoghurt samples increased from 1.22% in control sample to 1.41% in YBG₄ yoghurt sample containing 2% β -glucan however, during storage, no significant ($p \leq 0.05$) changes were reported in acidity values within yoghurt samples containing different concentration of β -glucan. Increase in the acidity of samples containing β -glucan could be due to β -glucan effect in increasing the production of acetic and propionic acids during fermentation. Similar results of increase in acidity due to its addition has been reported by Nikoofar et al. (2013) on studying the effect of oat β -glucan on non-fat set yoghurt.

Effect of β glucan addition on yoghurt pH values

The pH value of yoghurt samples decreased with increase in β -glucan content and varied from 4.69 for control sample to 4.00 for YBG₄ (yoghurt sample containing 2% β -glucan) as shown in Fig. 2b. During the first day of storage, pH of YBG₄ yoghurt sample obtained was 4.0, which further decreased to minimum value of 3.7 after 14 days of storage. The decline in pH during storage might be due to the utilization of residual carbohydrates by viable microorganisms and production of lactic acid as well as due to small amounts of CO₂ and formic acid from lactose (Nikoofar et al. 2013). The decrease in pH is due to the microorganism's activity, whereas some researchers

Fig. 1 Dynamic rheological characteristics of isolated barley beta glucan **a** shear stress versus shear rate **b** complex viscosity versus temperature

Fig. 2 Effect of β -glucan addition and storage on the **a** acidity, **b** pH, **c** syneresis values of yoghurt samples

demonstrated that the decline in pH during storage period was the result of residual enzymes produced by starters during fermentation (Christopher et al. 2009).

Effect of β glucan addition on syneresis values of yoghurt

Whey separation is an important defect in yoghurt and can be defined as the appearance of whey (serum) on the gel surface of yoghurt. Syneresis is defined as the shrinkage of the gel, which then causes whey separation. Manufacturers try to diminish whey separation by raising the total solids content of milk or by incorporating stabilizers such as gums and starches. In the current study changes in syneresis values of yoghurt samples during 14 days of storage indicated that the addition of β -glucan in the yoghurt led significant ($p \leq 0.05$) decrease in syneresis values as shown in Fig. 2c. This could be due to fact that high molecular weight of β -glucan had improved the water holding capacity of the yoghurt (Zhao et al. 2014) and prevented the weeping of water on the surface. As can be observed, the control samples showed lower WHC than the enriched yogurts ($p < 0.05$) during the whole period of cold storage, the yoghurt sample YBG₂ containing 0.5% β -glucan had syneresis level comparable to the control sample which further decreased to 65% with increase in glucan level. For the yoghurt sample YBG₄ containing 2% β -glucan, significant ($p \leq 0.05$) decrease was observed in syneresis values during storage period, which was 71% at first day and reduced to 65% on 14th day of storage. These results are in agreement with previous studies by Guzel-Seydim et al. (2005). Vanegas-Azuero and Gutiérrez (2018) observed that β -glucan enrichment of yoghurt reduces the synresis problem during storage when added even at higher levels.

Rheological characteristics

Effect of β glucan addition on yoghurt viscosity

The β -glucan has the ability to entrap water within the three-dimensional network of the product. Therefore, β -glucan added samples had shown more viscosity than control samples, which indicated that β -glucan helps to maintain structure of the yoghurt. A reduction in fat content can be achieved by replacing β -glucan with water and several ingredients to control water and to provide the functionality of that of reduced fat (Jirdehi et al. 2013). Fig. S2 (a–c) shows significant ($p \leq 0.05$) changes in viscosity values of yoghurt samples during storage. In our studies, viscosity was measured at different shear rate (rpm) and results showed that with increasing β -glucan concentration the values of viscosity increased from

3500 cP (control) to 6800 cP (YBG₄ yoghurt sample). However, viscosity values of yoghurt sample indicated a little change from 1180 to 1380 cP, throughout the storage period. This change could be attributed to the protein rearrangement and protein–protein interactions. Likewise, it is reported that the viscosity of β -glucan in the presence of starch that probably related to the hydrophobicity of the hydrogen-bonded regions of amylose and β -glucan may be responsible for such destabilization (Jirdehi et al. 2013).

The results of the power law model constants (n and K values) are shown in Table 2. The yoghurt samples behaved like *pseudo-plastic* fluids as evidenced by the flow behavior index ($n < 1$). A similar observation was obtained by Cruz et al. (2013a, b) in variably fat containing yoghurt samples. As compared to control (without β -glucan), yoghurt samples with added β -glucan had a higher consistency coefficient (K) which indicated a comparatively thicker compact texture of the yoghurts with added β -glucan. Inglett et al. (2015) reported that the pasting properties increase in the presence of β -glucan with increase in its content.

Texture profile analysis (TPA)

Results of texture profile analysis (TPA) of yoghurt samples are shown in Table 3. The values of hardness increased with the addition of the β -glucan in the yoghurt. The minimum value of hardness (0.253 N) was noted for control sample which increased to a maximum value of 0.454 N for yoghurt sample YBG₄. During 14th days of storage, further improvement in the hardness of yoghurt samples was noted and reached to a peak value of 0.687 N for yoghurt sample YBG₄. The increase in hardness values may be due to viscosity increase which could be attributed to ability of the β -glucan to entrap water within the three-dimensional network of the product. This indicated that β -glucan helps to maintain structure of the yoghurt (Guzel-Seydim et al. 2005).

The adhesiveness values of the yoghurt samples declined with the addition of the β -glucan from -1.490 N s for control sample to -2.530 N s for yoghurt sample YBG₄. During storage period a further drop was observed and reached to a minimum value of -4.058 N s. The decrease in adhesiveness may be attributed to β -glucan which helped to maintain the structure of the yoghurt, even during chewing of yoghurt to reduce adherence of yoghurt with teeth. However, during prolonged storage for the samples containing higher β -glucan, adhesiveness further increased. This might be due to decrease in syneresis which caused some dryness/compactness on the surface and decreased cohesiveness and caused increases in adhesiveness.

Table 2 Changes in flow consistency index (K), flow behavior index (n) and viscosity (η) of control and β -glucan added yoghurt samples during storage

Sample types	Number of days		7th day				14th day			
			1st day							
	η (cP)	σ (Pa)	n	K (Pa s)	η (cP)	Σ (Pa)	n	K (Pa s)	η (cP)	σ (Pa)
Control	960 $\pm$ 35 ^d	57,600 $\pm$ 102 ^c	0.157	4.159	1110 $\pm$ 55 ^c	66,600 $\pm$ 220 ^e	0.114	4.366	1360 $\pm$ 15 ^b	81,600 $\pm$ 230 ^d
YBG ₁	1180 $\pm$ 34 ^c	70,800 $\pm$ 110 ^d	0.126	4.344	1120 $\pm$ 85 ^c	67,200 $\pm$ 203 ^d	0.112	4.379	1380 $\pm$ 20 ^b	82,800 $\pm$ 180 ^c
YBG ₂	1240 $\pm$ 27 ^b	74,400 $\pm$ 85 ^c	0.122	4.373	1530 $\pm$ 88 ^b	91,800 $\pm$ 295 ^c	0.130	4.414	1300 $\pm$ 22 ^c	78,000 $\pm$ 129 ^e
YBG ₃	1280 $\pm$ 36 ^b	76,800 $\pm$ 115 ^b	0.121	4.389	1710 $\pm$ 90 ^a	102,600 $\pm$ 199 ^b	0.136	4.448	1540 $\pm$ 40 ^a	92,400 $\pm$ 297 ^b
YBG ₄	1620 $\pm$ 41 ^a	97,200 $\pm$ 130 ^a	0.125	4.468	1730 $\pm$ 95 ^a	103,800 $\pm$ 180 ^a	0.134	4.475	1560 $\pm$ 20 ^a	93,600 $\pm$ 235 ^a

The values are mean $\pm$ SD ($n = 3$) followed by different letters superscript in the same column are significantly different ($p \leq 0.05$), (control = yoghurt without β -glucan, YBG₁ = yoghurt + 0.5% β -glucan, YBG₂ = yoghurt + 1% β -glucan, YBG₃ = yoghurt + 1.5% β -glucan, and YBG₄ = yoghurt + 2% β -glucan)

Table 3 Texture profile analysis (TPA) of control and β -glucan added yoghurt samples

TPA characteristics	No. of days	Yoghurt samples				
		Control	YBG ₁	YBG ₂	YBG ₃	YBG ₄
Hardness (N)	1	0.253 $\pm$ 0.06 ^{Cd}	0.274 $\pm$ 0.00 ^{Ce}	0.297 $\pm$ 0.05 ^{Cb}	0.311 $\pm$ 0.05 ^{Cc}	0.454 $\pm$ 0.02 ^{Ca}
	7	0.264 $\pm$ 0.08 ^{Be}	0.339 $\pm$ 0.04 ^{Bc}	0.350 $\pm$ 0.03 ^{Bd}	0.378 $\pm$ 0.10 ^{Bb}	0.431 $\pm$ 0.01 ^{Ba}
	14	0.339 $\pm$ 0.07 ^{Ae}	0.394 $\pm$ 0.06 ^{Ad}	0.481 $\pm$ 0.05 ^{Ac}	0.534 $\pm$ 0.05 ^{Ab}	0.687 $\pm$ 0.06 ^{Aa}
Adhesiveness (N s)	1	– 0.930 $\pm$ 0.02 ^{Ce}	– 1.166 $\pm$ 0.04 ^{Cd}	– 1.487 $\pm$ 0.00 ^{Cc}	– 2.331 $\pm$ 0.06 ^{Bb}	– 2.530 $\pm$ 0.03 ^{Ba}
	7	– 1.490 $\pm$ 0.03 ^{Bc}	– 2.295 $\pm$ 0.05 ^{Bb}	– 3.223 $\pm$ 0.005 ^{Ac}	– 4.157 $\pm$ 0.00 ^{Ad}	– 4.058 $\pm$ 0.05 ^{Aa}
	14	– 1.932 $\pm$ 0.03 ^{Ab}	– 2.300 $\pm$ 0.07 ^{Aa}	– 2.535 $\pm$ 0.00 ^{Ba}	– 2.237 $\pm$ 0.00 ^{Cd}	– 2.345 $\pm$ 0.00 ^{Cb}
Cohesiveness	1	0.568 $\pm$ 0.01 ^{Ce}	0.652 $\pm$ 0.04 ^{Cd}	0.844 $\pm$ 0.004 ^{Bc}	0.955 $\pm$ 0.05 ^{Cb}	1.445 $\pm$ 0.06 ^{Aa}
	7	1.515 $\pm$ 0.01 ^{Ae}	1.730 $\pm$ 0.02 ^{Ad}	1.780 $\pm$ 0.04 ^{Ac}	1.785 $\pm$ 0.007 ^{Ab}	1.794 $\pm$ 0.04 ^{Aa}
	14	0.637 $\pm$ 0.03 ^{Be}	0.761 $\pm$ 0.08 ^{Bd}	0.777 $\pm$ 0.05 ^{Cc}	0.801 $\pm$ 0.03 ^{Bb}	0.990 $\pm$ 0.10 ^{Ca}
Gumminess	1	14.678 $\pm$ 0.01 ^{Ca}	13.240 $\pm$ 0.03 ^{Cb}	12.150 $\pm$ 0.02 ^{Cc}	11.752 $\pm$ 0.04 ^{Cd}	10.596 $\pm$ 0.04 ^{Ce}
	7	27.328 $\pm$ 0.01 ^{Ba}	26.309 $\pm$ 0.04 ^{Bb}	24.608 $\pm$ 0.05 ^{Bd}	24.177 $\pm$ 0.06 ^{Be}	25.476 $\pm$ 0.05 ^{Bc}
	14	34.219 $\pm$ 0.09 ^{Aa}	35.614 $\pm$ 0.04 ^{Ab}	34.015 $\pm$ 0.05 ^{Ac}	34.402 $\pm$ 0.08 ^{Ad}	30.762 $\pm$ 0.09 ^{Ae}
Chewiness	1	14.547 $\pm$ 0.07 ^{Aa}	10.819 $\pm$ 0.08 ^{Bc}	13.286 $\pm$ 0.09 ^{Aa}	14.285 $\pm$ 0.05 ^{Ac}	14.420 $\pm$ 0.06 ^{Ab}
	7	12.015 $\pm$ 0.04 ^{Ca}	10.730 $\pm$ 0.02 ^{Cb}	9.690 $\pm$ 0.04 ^{Cc}	9.605 $\pm$ 0.03 ^{Cd}	9.601 $\pm$ 0.07 ^{Be}
	14	13.529 $\pm$ 0.07 ^{Bb}	14.607 $\pm$ 0.08 ^{Aa}	12.072 $\pm$ 0.09 ^{Bc}	11.059 $\pm$ 0.01 ^{Bd}	9.090 $\pm$ 0.08 ^{Ce}
Springiness (%)	1	95.696 $\pm$ 0.10 ^{Ce}	96.252 $\pm$ 0.16 ^{Bc}	97.471 $\pm$ 0.11 ^{Ab}	98.839 $\pm$ 0.09 ^{Aa}	97.017 $\pm$ 0.08 ^{Bd}
	7	95.769 $\pm$ 0.08 ^{Bc}	99.240 $\pm$ 0.04 ^{Aa}	93.246 $\pm$ 0.07 ^{Ce}	91.720 $\pm$ 0.03 ^{Bd}	96.529 $\pm$ 0.07 ^{Cb}
	14	97.984 $\pm$ 0.17 ^{Ac}	96.067 $\pm$ 0.12 ^{Ce}	96.135 $\pm$ 0.05 ^{Bd}	98.909 $\pm$ 0.04 ^{Ab}	99.010 $\pm$ 0.15 ^{Aa}
Resilience (%)	1	4.141 $\pm$ 0.17 ^{Bd}	4.895 $\pm$ 0.10 ^{Ae}	5.792 $\pm$ 0.11 ^{Bc}	6.121 $\pm$ 0.15 ^{Bb}	10.141 $\pm$ 0.00 ^{Aa}
	7	4.470 $\pm$ 0.07 ^{Ab}	4.581 $\pm$ 0.09 ^{Bc}	3.694 $\pm$ 0.08 ^{Cb}	4.211 $\pm$ 0.09 ^{Cc}	4.682 $\pm$ 0.09 ^{Ca}
	14	4.135 $\pm$ 0.05 ^{Bd}	4.142 $\pm$ 0.07 ^{Ce}	6.766 $\pm$ 0.08 ^{Ac}	7.588 $\pm$ 0.08 ^{Ab}	8.334 $\pm$ 0.10 ^{Ba}

The values are mean $\pm$ SD (n = 3) followed by different small letters superscript in the same row and capital letters in the column for respective characteristic are significantly different ($p \leq 0.05$). (Control = yoghurt without β -glucan, YBG₁ = yoghurt + 0.5% β -glucan, YBG₂ = yoghurt + 1% β -glucan, YBG₃ = yoghurt + 1.5% β -glucan, and YBG₄ = yoghurt + 2% β -glucan)

Since β -glucans could cause the formation of protein aggregates to produce gels through hydrophobic interactions (Zhao et al. 2014), which had imparted crumbly texture to the yoghurt. However, there was a significant increase in the adhesiveness in the yoghurt samples containing higher β -glucan level and stored for 14 days. This could be attributed to substantial increase in compactness of these samples which might have made the surface compact and little more adhesive. On an average, the results indicated that yoghurt samples without β -glucan were less hard and more adhesive than β -glucan added yoghurt samples.

Decrease in gumminess was also reported for yoghurt samples with increase in the amounts of β -glucan. Yoghurt samples without β -glucan (control samples) had more gumminess (14.678) as compared to yoghurt sample YBG₄ (10.596). During storage a significant increase in gumminess was observed, which might be due to increased hardness of the yoghurt sample. No significant differences were obtained for springiness values of yoghurt containing different concentration of β -glucan and control sample.

In TPA test results, the value of cohesiveness for YBG₄ yoghurt sample was more (1.445) as compare to control sample (0.568). Resilience as a parameter of TPA, increased with the addition of β -glucan in yoghurt. During the first day, the resilience value was 4.141% for control sample which increased further during storage period to 10.141% with addition of maximum level (2%) of β -glucan in yoghurt sample YBG₄. The reasons for these changes may be the interaction between β -glucan (polysaccharide) and casein micelles and the ability of the β -glucan to entrap water within the three-dimensional network of the yoghurt. β -Glucan has the ability to form gel with protein and has the ability to maintain structure (Kruif and Tuinier 2011), as in case of yoghurt. On an average, results of textural profile tests showed appropriate hardness, less gumminess, less adhesiveness and less destruction of gel structure in yoghurt samples containing β -glucan giving firm and creamy texture that was near to creamy mouth feel of full fat yoghurt. Overall β -glucan addition had improved the mouth feel characteristics thereby enhanced sensory appeal for the product in which incorporated.

Table 4 Average sensory scores of control and β -glucan added yoghurt samples

Sensory characteristics							
Yoghurt sample	Physical appearance	Kinesthetic			Taste	Color	Overall acceptability
		Hardness	Cohesiveness	Adhesiveness			
Control	7.5 $\pm$ 0.21 ^b	7.5 $\pm$ 0.21 ^b	7.5 $\pm$ 0.45 ^b	7 $\pm$ 0.35 ^d	8 $\pm$ 0.76 ^c	8.0 $\pm$ 0.15 ^c	7.3 $\pm$ 0.07 ^c
YBG ₁	7.0 $\pm$ 0.25 ^c	7.0 $\pm$ 0.25 ^c	7.5 $\pm$ 0.51 ^b	8.0 $\pm$ 0.6 ^c	8.0 $\pm$ 0.45 ^c	8.0 $\pm$ 0.15 ^b	7.6 $\pm$ 0.05 ^b
YBG ₂	7.5 $\pm$ 0.50 ^b	7.5 $\pm$ 0.45 ^b	7.5 $\pm$ 0.25 ^b	8.5 $\pm$ 0.35 ^b	8.5 $\pm$ 0.50 ^b	8.0 $\pm$ 0.30 ^b	7.8 $\pm$ 0.06 ^b
YBG ₃	7.5 $\pm$ 0.15 ^b	8.0 $\pm$ 0.56 ^a	8.0 $\pm$ 0.30 ^a	8.5 $\pm$ 0.35 ^b	9.0 $\pm$ 0.55 ^a	8.5 $\pm$ 0.45 ^a	8.1 $\pm$ 0.03 ^a
YBG ₄	8.0 $\pm$ 0.25 ^a	8.0 $\pm$ 0.57 ^a	8.0 $\pm$ 0.50 ^a	9.0 $\pm$ 0.15 ^a	9.0 $\pm$ 0.25 ^a	8.5 $\pm$ 0.45 ^a	8.2 $\pm$ 0.05 ^a

The values are mean $\pm$ SD (n = 30) followed by different letters superscript in the same column are significantly different ($p \leq 0.05$). (Control = yoghurt without β -glucan, YBG₁ = yoghurt + 0.5% β -glucan, YBG₂ = yoghurt + 1% β -glucan, YBG₃ = yoghurt + 1.5% β -glucan, and YBG₄ = yoghurt + 2% β -glucan)

Sensory evaluation of yoghurt

The average sensory scores of panelists are shown in Table 4. The sensory results indicated that there was statistically significant ($p \leq 0.05$) difference in the sensory characteristics of yoghurt samples such as control and β -glucan added samples. The average overall acceptability increased with increase in the amount of β -glucan in the sample and a maximum value of 8.16 ± 0.25 was obtained for yoghurt sample YBG₄ containing 2% β -glucan. It was observed that the addition of β -glucan from 0.5% up to 1% did not have positive effect on the acceptability of the yoghurt to a great extent, wherein, yoghurt sample YBG₄ containing 2% β -glucan had highest acceptability value of 8.20 ± 0.05 followed by YBG₃ yoghurt sample (8.1 ± 0.03). In contrast to this, control sample had lowest acceptability value of 7.3 ± 0.07 . The sensory test report indicated that almost all β -glucan added yoghurt samples had average sensory scores of above 7 (Like moderately), considered in the present work as the minimum acceptable value.

In case of physical appearance of yoghurt, whey separation was the main parameter. Control yoghurt sample and formulation containing different levels of β -glucan up to 1% received the same score for this parameter, however at higher levels of β -glucan addition, improvement in the sensory perceptions for appearance was observed. Sensory attribute such as color, was also not much affected by the incorporation of β -glucan into the formulation. Similar results were found by Patel et al. (2012) who reported that polysaccharide could improve the quality of yoghurt, while having no effect on the color of yoghurt, therefore, could replace some stabilizer. The maximum compression force for YBG₄ and YBG₃ yoghurt samples could be related to their highest sensory scores for texture. The higher maximum force could be explained by the sample hardness

characteristics and in turn could be related to panelist's preference for firmer yoghurts.

Conclusion

The results of the present work showed that incorporation of β -glucan in the yoghurt had significant influence on the rheological and physiochemical parameters of yoghurt increase the sensory and mouth feel characteristics. The yoghurt fortified with the β -glucan had less syneresis defect, improved viscosity and texture as compared to the control sample whereas, maximum changes were observed in the sample containing higher concentration of β -glucan. Inclusion of β -glucan into yoghurt not only improved the rheological, physiochemical and sensory properties of the yoghurt but also improved the nutritional values by acting as prebiotic in probiotic yoghurt. Therefore, yoghurt containing β -glucan could be an innovative healthy product for enhancing β -glucan consumption in the diet.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval The ethical approval for this study has been taken from the departmental concern as per the set procedure followed through a committee comprising (HOD, FE&T), Prof. & PG Coordinator (Dr. Sukhcharn Singh) and Dr. Kamlesh Prasad, (Professor, FE&T). The written consent from participants including staff and students of the FE&T Department as per requirements have been taken for carrying out the sensory analysis of the developed product and has been kept in record.

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