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ORIGINAL ARTICLE

Effect of β-glucan fortification on physico-chemical, rheological, textural, colour and organoleptic characteristics of low fat dahi

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Abstract Fortified low fat functional dahi prepared by supplementing skimmed buffalo milk with β-glucan (0.25, 0.50, 0.75 and 1.0%) was assessed for physico-chemical, rheological, textural, colour and sensorial characteristics. Total solids in dahi increased significantly with the increase in β-glucan concentration, however, values of fat, protein and ash varied non-significantly upon β-glucan addition in dahi. β-glucan at 0.5% solids levels, produced low fat dahi with superior quality, less whey separation and good textural properties than the samples containing other levels. Syneresis and viscosity was positively affected with the addition of β-glucan till 0.5% level and higher concentration caused destabilization of the product. Fortified dahi showed greater firmness and consistent than control dahi sample. The addition of 0.5% level of β-glucan also imparted significantly better instrumental color values and sensory scores with attractive or natural dahi color when compared to control dahi samples and other dahi samples prepared with different levels of β-glucan.

Keywords Dahi · β-Glucan · Textural properties · Low fat · Buffalo milk

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Introduction

Fermented dairy products constitute a vital component of the human diet globally. *Dahi*, popular nourishing fermented dairy product, is an ideal diet for those having sensitive digestive systems, particularly young children and elderly persons. It is also used as a good vehicle to provide health benefits to consumers, because of the fact that it is consumed by people daily in Indian sub-continent. The rising concept of functional foods put pressure on dairy/food scientists to modify basic food commodity in a way to improve nutritional status and marketability of the functional foods. In response to this, incorporation of nutraceuticals in regularly consumed food products presents an opportunity to prevent and manage common health problems. The market size of fortified/functional foods worldwide in 2014 was recorded 258.8 billion U.S. dollars and projected to reach 377.8 billion U.S. dollars by 2020 (http://www.statista.com), with a growth rate of 7.66%, whereas in India, it is growing at a compound annual growth rate of 17.1% (http://www.ingredientssouthasia.com).

Urbanization has led to the growth of ready-to-eat food products with inferior nutritional quality. Poor nutrition has resulted in more people around the world dying from obesity than starvation and therefore, has been recognized as a major risk factor for chronic diseases (Anscombe et al. 2014). Thus, a balanced approach between taste, nutrition and expenses creates a challenge for professionals to develop good tasting low caloric food products. However, the elimination or reduction of fat in foodstuffs not only modifies composition and structure, but also the interactions among the various constituents, giving rise to clearly perceptible changes in color, flavor and texture (Bayarri et al. 2011), and possibly to less acceptable products.

Furthermore, low total solids in dairy products like *dahi* without any fortification can result in whey expulsion, weak body, poor texture and inconsistent product. To address issues related with fat reduction or elimination, one of the most frequent strategies is the use of fat replacers or fat mimetic which compensates this shortcoming.

Carbohydrate-based fat replacers, such as carrageenan, guar gum and inulin, have been used safely as thickeners and stabilizers especially in sauces, dressing formulations and in dairy products (cheese and yoghurt). More recently, soluble dietary fibers, such as (1–3, 1–4) β-D-glucan (hereafter referred as β-glucan), from oat and barley have received considerable attention with regard to their hypoglycemic and hypocholesterolemic capacity in humans and also in relation to a reduction in the incidence of diabetes (Li et al. 2003) and cardiovascular disease (Keogh et al. 2003; Lyly et al. 2003).

Barley is a rich source of β-glucan, but consumption of products containing barley grain or flour is often limited by their negative organoleptic quality. β-glucan has already been used in many foods as a functional ingredient, including pasta, oat flakes, cereals, bakery products, beverages and meat products (Morin et al. 2004), but not much explored in dairy products. In addition to nutraceutical properties, potential benefits of β-glucan are also related to its rheological properties, mainly its ability to increase viscosity and gel forming capacity (Brennan 2004). These attributes makes it an attractive option to be added into dairy products to improve texture and acceptability.

Till date, there are limited numbers of studies in the literature concerning the use of β-glucan in the preparation of fermented dairy products especially in *dahi*. Moreover, despite the increasing interest in nutraceuticals and functional foods in India, dairy products fortified with different functional ingredients are limited. The only bioactive ingredients used in functional dairy products in the present market include omega 3-fatty acids, plant sterols and bioactive peptides. Thus, the present study has been designed to develop a low-fat functional *dahi* which combines the nutritional properties of both milk and β-glucan.

Materials and methods

Raw materials

Buffalo skim milk

Fresh buffalo milk was procured from the Experimental Dairy Plant of the College of Dairy Science and Technology, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana. Buffalo skimmed milk was prepared by separating fat from fresh buffalo milk at 45 °C.

Starter culture

Mixed mesophilic starter culture i.e. NCDC-167, in freeze-dried form, for *dahi* preparation was purchased from the National Collection of Dairy Cultures (NCDC), ICAR-National Dairy Research Institute, Karnal, India. The starter culture was maintained in autoclaved reconstituted skimmed milk (total solids 12 g/100 ml) by sub-culturing once in a fortnight for attaining high activity. Skimmed milk powder used for reconstitution was purchased from the outlet of Verka Milk Plant, Punjab State Cooperative Milk Federation Dairy, Ludhiana, India.

β-glucan

Commercial food grade β-glucan, a soluble dietary fiber obtained from barley, in the form of brownish powder under brand name Glucagel^{TM} (having non β-glucan carbohydrate <15%, β-glucan ≥75%, moisture <10%, protein <5%, lipid <2%, ash <2% and tapped density ≥0.25 g/ml) was gifted by DKSH, Italy. To estimate β-glucan, the β-Glucan Assay Kit (mixed linkage) make Megazyme, Ireland International was procured from Pro Lab Marketing Pvt. Ltd. New Delhi.

Chemicals and reagents

All the chemicals and reagents of analytical grade (AR) and media for microbiological analysis used in the study were procured from Himedia Laboratories, Mumbai.

High intensity polystyrene packaging cups

Unprinted high intensity polystyrene (HIPS) packaging cups of 100 ml capacity with lids were procured from Century Ultrapack Pvt. Ltd, Greater Noida, UP, India.

Product formulation

Preparation of dahi

Dahi samples of 2 kg lot in each trial were prepared under hygienic condition as per the method described by Aneja et al. (2012) with slight modifications. Weighed amount of β-glucan (0.25–1%) was added gradually in buffalo skimmed milk at 45 °C just after filtration and mixed at 14,000 rpm for 6–7 min with the help of T25 digital high speed homogenizer, Ultra Turrax (IKA, Germany). Then, the intermediate product was heat treated to 90 °C for

15 min followed by cooling to 37 ± 1 °C. Thereafter, fortified milk samples were inoculated with culture (NCDC-167) @2.5% for *dahi* preparation in Laminar Air Flow.

Filling, sealing and storage

After inoculation, cultured milk was transferred to pre sterilized (via UV) HIPS cups and sealed with pre sterilized lids. Then, the filled cups were transferred to incubator and incubated at 37 °C for the same time as pH reaching 4.6. The set curd was further transferred in refrigerator for storage at 4 ± 1 °C.

Chemical characteristics

The total solids, ash and titratable acidity of buffalo skim milk and *dahi* samples were determined as per the method described in BIS (2001). The fat percentage of buffalo skim milk and *dahi* samples were determined with the help of Mojonnier fat extraction apparatus as specified in BIS (2001). The protein content of buffalo skim milk and *dahi* samples was determined by semi-micro Kjeldahl method (Kelplus, Pelican Equipments, India) as described in BIS (2001). Lactose content of buffalo skim milk was estimated as per Lane and Eynon method as described in BIS (2001), while the total carbohydrate content of all dahi samples was estimated by differential method (AOAC 1997). The pH of all samples was determined using digital pH meter (Oakton, Eutech instruments, Switzerland).

Physical and rheological characteristics

Syneresis of *dahi* samples was determined using the method described by Shekhar et al. (2013). The viscosity of *dahi* samples was determined using a Brookfield viscometer (model LVDV-IIPro, Brookfield, Labomat Essor, Saint-Denis, France) at 50 rpm.

Texture profile analysis of functional *dahi*

Instrumental textural attributes of β-glucan *dahi* samples were measured in terms of firmness, consistency, cohesiveness and index of viscosity using Texture Analyzer TA-XT Plus (M/s Stable Micro Systems, Surrey, UK) controlled with exponent software (version 6.1.1.0). Readings were taken five times and the means were reported. A back extrusion test using 35 mm cylinder probe was used for texture profile analysis of the samples. The product was subjected to compressive force by probe up to the distance of 30 mm. The conditions set in the texture analyzer for measuring textural properties were as follows: pre-test, post-test and test speed, 1 mm/s; time, 5.0 s; trigger force, 5.0 g and load cell, 5.0 kg. For each evaluation, $(3 \times 3 \times 2.5)$ cm^3 size sample was used during texture analysis.

Instrumental color (L*a*b* color values and hue angle)

Surface color of milk and low fat *dahi* samples were measured using Color Flex Colorimeter (Hunter lab, Reston, Virginia) supplied along with the universal software Easy Match QC (version 4.62) and the results were expressed in terms of CIE-LAB system. The colorimeter was equipped with dual beam xenon flash lamp as source of light. Prior to analyzing the samples, the instrument was calibrated with standard black glass and white tile as specified by the manufacturer. Data was received through the software in terms of values for L* (lightness), 0 (black) to 100 (white); a* (redness), +60 (red) to −60 (green) and b* (yellowness), +60 (yellow) to −60 (blue). To calculate hue angle of *dahi* samples, the procedure of Khatkar and Gupta (2014b) with the following formula was used:

$$\text{Hue angle} = a\tan(b^*/a^*)^{-1}$$

Sensory analysis

A sensory panel consisting of seven semi-trained panelists was selected from the faculty of College of Dairy Sciences and Technology, GADVASU, Ludhiana to evaluate the samples for their sensory attributes. Each panelist was served all the samples, which were evaluated for sensory attributes such as flavor, texture, color and appearance, mouth feel and overall acceptability on 9 point Hedonic scale. A sample of each treatment was drawn randomly from refrigerator just before serving and was served to each panelist for judging (Raju and Pal 2014). The color and appearance scores were given based on the color of *dahi* and the presence or absence of whey. The texture of *dahi* was evaluated on the basis of firmness, thickness and cutting behavior of *dahi*. Flavor scores were mainly based on the freshness and acidity of the sample. Mouthfeel of the *dahi* was evaluated on the basis of consistency and feeling of texture of *dahi* samples in mouth. On the basis of above mentioned sensory characteristics, overall acceptability scores were given by the panelists. Sensory score of 6.5 or above were considered to be commercially acceptable.

Statistical analysis

Data reported in the tables are expressed as mean values with standard deviations. In all experiments, one way analysis of variance without interaction using SPSS 22.0

version, wherever required, with a subsequent least significant difference (with CD_{LSD} equation) test was applied for multiple sample comparison to test for any significant difference ($P < 0.05$ and $P < 0.01$) in the mean values of all the groups.

Results and discussion

Proximate composition of buffalo skim milk

Buffalo skim milk had total solids, 11.99 ± 0.20%; fat, 0.27 ± 0.16%; protein, 4.52 ± 0.23%; lactose, 5.92 ± 0.34%; ash 0.836 ± 0.01%; acidity, 0.14 ± 0.03% lactic acid and pH, 6.6 ± 0.01 (n = 9). The values for proximate composition were found to lie within the normal range, but slightly higher amount of different constituents to what has been reported earlier (Khatkar and Gupta 2014a) that could be due to batch type handling of small quantity of milk to avoid flushing procedure in the plant.

Effect of β-glucan addition on physico-chemical properties of low fat *dahi*

The physico-chemical properties of *dahi* samples with different solids level of β-glucan are presented in Table 1. The total solids content was observed to increase gradually and significantly ($P < 0.01$) from control sample i.e. skim milk *dahi* without β-glucan (11.99%) to sample with 1% β-glucan level (12.81%). The gradual increase in the total solids was due to the addition of β-glucan as an extra source of solids to the milk. Ramanathan and Sivakumar (2013) observed the similar trend in total solids in the *dahi* fortified with oat fiber. However, no significant difference was observed between control sample and sample containing 0.25% solids level of β-glucan. Non-significant effect of β-glucan addition was observed on fat content of all experimental samples with values ranging between 0.25 and 0.28%. Similarly, protein content did not vary significantly upon β-glucan addition in *dahi*. Total carbohydrates were noted to increase significantly ($P < 0.05$) from 6.37% in control *dahi* samples to 7.14% in *dahi* samples containing 1% β-glucan. As β-glucan is a carbohydrate polymer, there was a proportionate increase in carbohydrate content of *dahi* with increasing β-glucan levels. Marginal and non-significant ($P < 0.05$) increase was observed in ash content of *dahi* with increase in β-glucan levels. Similar trend was established for titratable acidity of control *dahi* and β-glucan supplemented *dahi*, however, the values were well within the normal range. Slight increase in acidity of *dahi* with increasing β-glucan concentrations could be due to β-glucan's effect on increasing the production of acetic and propionic acids during fermentation (Nikoofar et al. 2013). *Dahi* containing different concentrations of β-glucan had lower pH value (4.63–4.59) than the control sample (4.66). Akalin et al. (2007) also reported that pH values of yoghurt containing fructo-oligosaccharides were lower than yoghurt without supplementation and similar observations were reported by Mahrous et al. (2014) in yoghurt containing oats.

Effect of β-glucan addition on physical and rheological properties of low fat *dahi*

Syneresis

Synerersis is the separation of whey from the curd and is indicative of the quality of *dahi*. Forced syneresis of control and β-glucan enriched *dahi* has been presented in Fig. 1. Syneresis value of control *dahi* sample was noted as 3.11 ml and for supplemented *dahi* the values ranged from 1.98 to 5.85 ml. Syneresis value decreased significantly

Table 1 Effect of addition of β-glucan at different solids level on physico-chemical composition of low fat dahi

Properties	Levels of β-glucan (%)					
	0	0.25	0.50	0.75	1.0	CD
Total solids (%)	11.99 ± 0.20[a]	12.21 ± 0.23[a,b]	12.44 ± 0.24[b,c]	12.67 ± 0.09[c,d]	12.81 ± 0.25[c,d,e]	0.525*/0.69**
Fat (%)	0.27 ± 0.16	0.25 ± 0.03	0.26 ± 0.05	0.28 ± 0.07	0.25 ± 0.09	NS
Protein (%)	4.52 ± 0.23	4.54 ± 0.30	4.53 ± 0.13	4.56 ± 0.15	4.54 ± 0.19	NS
Total CHO (%)	6.37 ± 0.32[a]	6.57 ± 0.26[a,b]	6.78 ± 0.30[b,c]	6.95 ± 0.31[c,d]	7.14 ± 0.21[c,d,e]	0.501*
Ash (%)	0.836 ± 0.01	0.850 ± 0.01	0.871 ± 0.01	0.881 ± 0.01	0.886 ± 0.001	NS
Acidity (% LA)	0.708 ± 0.03	0.730 ± 0.02	0.742 ± 0.02	0.755 ± 0.03	0.756 ± 0.04	NS
pH	4.66 ± 0.01	4.63 ± 0.02	4.62 ± 0.02	4.59 ± 0.02	4.60 ± 0.03	NS

Means with the same superscript in a row are not significantly different

n = 9

* Significant at $P < 0.05$

** Significant at $P < 0.01$

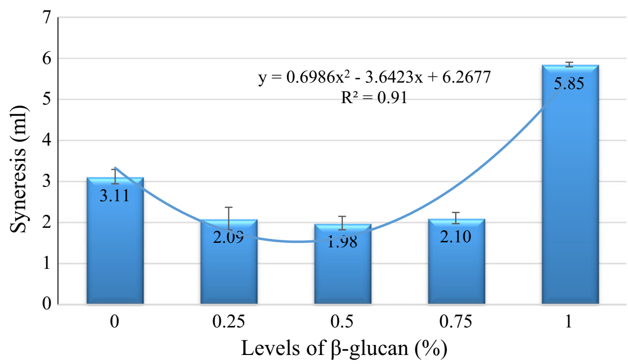

Fig. 1 Effect of addition of different solids level of β-glucan on syneresis

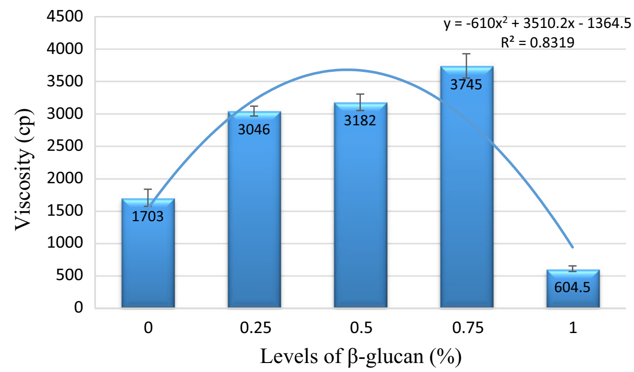

Fig. 2 Effect of addition of different solids level of β-glucan on viscosity

($P < 0.01$) upon incorporation of β-glucan in *dahi* up to 0.75% and thereafter at 1% level, sudden increase in syneresis value was observed. A polynomial trend for syneresis was observed among dahi samples. Initially a decreasing trend was observed up to sample with 0.5% solids level of β-glucan (1.98) in *dahi*, thereafter syneresis value started increasing gradually at certain level due to destabilization of the product network with 0.75% (2.10) to 1% solids level (5.85). This behavior could be attributed to poor heat stability of milk proteins and β-glucan leading to phase separation (protein rich and polysaccharide rich phases), a concentration dependent response (Vasiljevic et al. 2007). Brennan and Tudorica (2008) reported that β-glucan in skim milk yoghurt decreased syneresis when compared to full fat milk yoghurt. The following observation might be due to β-glucan's ability to form three dimensional network entrapping water.This effect could also be related to gelling capacity of β-glucan and their ability to form cross link gel network and elastic casein–protein–glucan matrix (Ozcan and Kurtuldu 2014). Similar trend were observed by Amaya-Llano et al. (2008) in stirred yoghurt.

Viscosity

Viscosity of *dahi* was positively affected with the addition of β-glucan at different solids level (Fig. 2). With the increase in the β-glucan concentration, there was a significant ($P < 0.01$) increase in the viscosity of *dahi* up to 0.75% and thereafter, sample with 1% solids level exhibited the lowest viscosity resulting in an unstable product. Control *dahi* samples had viscosity of 1703 cp which increased significantly ($P < 0.01$) to 3046 cp at 0.25% β-glucan level. The highest viscosity was measured at 0.75% β-glucan level (3745 cp) and the lowest at 1% level (604.50 cp). Similar trend was observed by Brennan and Tudorica (2008) in low fat yoghurt and Amaya-Llano et al. (2008) in stirred yoghurt. Improvement in product viscosity is likely related to increased total solids and hydro-colloidal properties of the β-glucan (Lee et al. 2009). Thus, the presence of β-glucan in *dahi* modifies its rheological properties and intensifies its gel like characteristics (Samadi et al. 2013). Fernandez-Gracia et al. (1998) reported that fiber addition resulted in significant increase in viscosity.

Remarkable correlation ($R^2 = 0.910$) was found between the syneresis values and β-glucan concentration of all *dahi* samples. Correlation value >0.9 depicts strong interaction between the two. Similarly, correlation value between *dahi* viscosity and β-glucan concentration was noted as $R^2 = 0.831$, establishing a strong relation among the two variables.

Effect of β-glucan addition on textural properties of low fat *dahi*

Texture of food can be characterized as a flow, deformation or disintegration of the food material under an applied force (Jaros and Rohm 2003). In order to assess the quality and manufacturing strategies of *dahi*, it is important to determine its textural attributes such as firmness, consistency and cohesiveness. For testing the aforementioned characteristics, back extrusion test was applied because it is well suited for gels as it is not affected by free whey on the surface of samples (Pereira et al. 2003).

Firmness

The firmness results of the control and β-glucan enriched *dahi* are summarized in Table 2. A highly significant difference ($P < 0.01$) was observed in the firmness values of *dahi* samples. The direct reason behind this can be ascribed to increase in total solids and interaction between milk solids and β-glucan. Similar results were quoted by Nikoofar et al. (2013), where the authors established that reduced fat yoghurt containing oat β-glucan had a firm and creamy texture. As per Brennan and Tudorica (2008), β-

Table 2 Effect of addition of β-glucan at different solids levels on textural properties of low fat dahi

Properties	Levels of β-glucan (%)					CD
	0	0.25	0.5	0.75	1	
Firmness (g)	385.53 ± 27.32^{a}	460.12 ± 24.21^{b}	491.53 ± 12.13^{b,c}	471.00 ± 22.28^{b,c,d}	149.55 ± 13.43^{e}	57.89*; 77.15**
Consistency (g s)	8983.88 ± 643.86^{a}	11,056.64 ± 497.10^{b}	11,586.44 ± 251.63^{b,c}	11,535.39 ± 518.87^{b,c,d}	3223.74 ± 250.49^{e}	1290.86*;1720.56**
Cohesiveness (g)	−176.77 ± 13.08^{a}	−195.83 ± 14.29^{a,b}	−204.80 ± 8.37^{a,b,c}	−219.58 ± 10.68^{b,c,d}	−83.13 ± 6.80^{e}	30.73*; 40.97**
Index of Viscosity (g s)	−330.72 ± 27.56^{a}	−375.24 ± 28.01^{a,b}	−389.79 ± 21.90^{a,b,c}	−410.90 ± 22.50^{b,c,d}	−128.66 ± 20.06^{e}	66.4*; 88.5**

Means with the same superscript in a row are not significantly different

n = 9

* Significant at $P < 0.05$

** Significant

glucan promotes self-association of casein resulting in increased gel strength and this will make yoghurt less susceptible to rearrangements within its network. This possibly explains the reason for increase in firmness values of *dahi* with increasing β-glucan levels. Increase in firmness values of the product was noticed up to a certain extent, and thereafter it started decreasing at higher levels (1% β-glucan) due to destabilization in the product. Garcia-Perez et al. (2005) reported that addition of orange fiber at 0.6 and 0.8% had a breakening effect in the gel structure of yoghurt. Higher fiber levels (0.75 and 1.0%) might have disrupted the gel network of *dahi* and led to lower firmness values.

Consistency

β-glucan enrichment led to significant difference ($P < 0.05/0.01$) in the consistencies between control *dahi* and *dahi* enriched with different solids level of β-glucan (Table 2). The consistency of the product increased up to 0.5% level of β-glucan, and thereafter, it decreased at higher concentrations. Samples with 1% solids level exhibited the lowest consistency as compared to all other groups. Among the groups' control, 0.25 and 1% solids level of β-glucan were found to be significantly different with each other, while there was no significant difference between samples containing 0.25, 0.5 and 0.75% solids level of β-glucan. The probable reason behind the increase in consistency might be due to increase in total solids and interaction between β-glucan and milk solids. Similar trends were observed by Brennan and Tudorica (2008) in dietary fiber enriched yoghurt. On the other hand, decreased consistency of *dahi* at higher β-glucan concentrations might be due to weak gel structure of *dahi* caused by high fibre concentrations, leading to disruption of *dahi* gel network.

Cohesiveness

Dahi samples enriched with β-glucan were found to be significantly different ($P < 0.05$) from control *dahi* with respect to cohesiveness values (Table 2). Cohesiveness of the *dahi* containing β-glucan depicted decreased trend with increase in β-glucan solids level, but at higher concentration (1.0%) sudden increase was observed in cohesiveness. Mohamed et al. (2014) found that addition of dried grape pomace as a dietary fibre in yoghurt decreased cohesiveness values and increased hardness with increasing pomace concentration. The control group varied significantly ($P < 0.05$) with 0.75 and 1% groups and exhibited no significant difference with samples having 0.25 and 0.5% solids level of β-glucan. Sample containing 1% β-glucan solids showed highly significant difference with all other groups.

Index of viscosity

Index of viscosity as measured by texture analyzer depicted a negative force value and was inversely proportional to viscosity (Table 2). The lowest index of viscosity was observed for *dahi* sample containing 0.75% β-glucan (−410.90 g s) and the highest for 1% β-glucan enriched *dahi* (−128.66 g s). The following observation explains the viscosity behaviour of *dahi* upon incorporation of β-glucan. Decrease in index of viscosity was observed with increased β-glucan concentration in *dahi,* but sudden increase was noted at 1% level. Mejri et al. (2014) also reported increase in yoghurt viscosity with increase in β-glucan content up to 1.5%. Increase in β-glucan content promotes increase in viscosity and consequent decrease in rate of formation of phase separated domains (Nikoofar et al. 2013), thereby, improving the textural attributes of *dahi*. However, levels above 0.75% cause destabilization of the product due to thermodynamic instability, and increases index of viscosity.

Addition of higher amount of β-glucan to low fat dahi resulted in caused to decrease in the textural attributes. This could mainly be due to the nature of interaction between β-glucan and casein micelles; the particles and polymer having no specific interaction, besides excluded volume. The polymers are, therefore, excluded from the surface of the sphere. This results in an effective depletion of internal network. So, the casein gel in this situation was weak and with less strength and flexibility accordingly (Nikoofar et al. 2013).

Effect of β-glucan addition on instrumental color values of *Dahi*

Dahi samples with varying solids level of β-glucan were evaluated for instrumental color analysis and results obtained are reported in Table 3.

L value*

L* values (whiteness value) of *dahi* samples with different solids level of β-glucan decreased significantly ($P < 0.05/0.01$) with the addition of β-glucan (Table 3). A linear trend could be observed i.e. increase in concentration of β-glucan in *dahi* gradually decreased L* values. Control *dahi* samples were noted to have L* value of 93.39. Raju and Pal (2014) reported that oat and soy fibre addition in *mishti dahi* reduced its L* value. In a study conducted on dietary fibre addition on probiotic *dahi*, Ozcan and Kurtuldu (2014) found that incorporation of barley-based and oat-based β-glucan in yoghurt lowered its L* value when compared to control. L* values of β-glucan enriched *dahi* was noted in the range of 92.40–84.68. Gradual decrease in the L*values might be ascribed to light brown color of β-glucan that resulted in the reduction of whiteness in the products with increased concentration. Also, significantly higher reduction of L* value at 1% β-glucan concentration as compared to *dahi* with lower β-glucan levels, could be attributed to the dense mass formed by the separation of the whey (Singh et al. 2012), as noted from high syneresis value at 1% β-glucan concentration.

a value*

There was a significant effect ($P < 0.05$) of β-glucan addition on a*value (redness) of *dahi* samples (Table 3). All the samples exhibited polynomial trends and maximum a* value was observed for *dahi* sample containing 0.75% β-glucan, whereas minimum value was noted for control *dahi*. Increase in redness with increasing concentration of β-glucan might be due to brownish color of β-glucan. As the solids level of β-glucan increased, the samples exhibited the increasing trends in a*value up to 0.75% solids level, and thereafter followed by decreasing trend. Highly significant differences ($P < 0.05$) were observed between control *dahi* (−1.64) and *dahi* containing variable β-glucan levels, however there was no significant ($P < 0.05$) difference between sample with 1% β-glucan and samples with 0.5 and 0.75% β-glucan. Increase in redness might be due to brownish color of β-glucan powder. Mejri et al. (2014) found that 1 and 1.5% β-glucan incorporation in non-fat yoghurt increased its red color. Oat β-glucan increased redness value of set-style yoghurt at concentrations greater than 0.3%, being the highest at 0.5% β-glucan level (Singh et al. 2012).

b value*

The addition of β-glucan in *dahi* affected its b* values and statistical analysis showed that all samples exhibited highly significant difference ($P < 0.01$) from control sample (Table 3). Yellowness of the products increased significantly from 12.28 (control) to 19.10 (1% β-glucan). This effect could be explained due to brownish color of β-glucan that directly imparts yellowness to the fortified samples. Raju and Pal (2014) observed that yellowness of *mishti dahi* increased upon inulin incorporation but decreased with oat incorporation. These might be due to the effect of sugar on color values of *dahi*. Singh et al. (2012) also observed increase in b* values with increasing β-glucan concentration in set yoghurt. Similar results were established by Damian (2013) in yoghurt containing apple fibre and inulin.

Table 3 Effect of addition of β-glucan at different solids levels on instrumental color values of dahi

Properties	Levels of β-glucan (%)					
	0	0.25	0.5	0.75	1	CD
L* values	93.39 ± 0.10[a]	92.40 ± 0.14[b]	91.65 ± 0.13[c]	90.30 ± 0.26[d]	84.68 ± 0.49[e]	0.589* 0.788**
a* values	−1.64 ± 0.12[a]	−0.81 ± 0.13[b]	−0.46 ± 0.10[c]	−0.12 ± 0.10[d]	−0.42 ± 0.06[c,d,e]	0.301* 0.401**
b* values	12.28 ± 0.11[a]	12.92 ± 0.03[b]	13.41 ± 0.09[c]	14.47 ± 0.22[d]	19.10 ± 0.05[e]	0.348* 0.457**
Hue angle (°)	−1.43 ± 0.01[a]	−1.50 ± 0.01[b]	−1.53 ± 0.00[c]	−1.56 ± 0.00[d]	−1.54 ± 0.00[c]	0.014* 0.016**

Means with the same superscript in a row are not significantly different

n = 9

* Significant at $P < 0.05$

** Significant at $P < 0.01$

Hue angle

Hue angle of *dahi* samples was observed to decrease with increasing β-glucan concentration. Maximum hue angle was observed for control *dahi* (−1.43) and minimum value was noted for *dahi* supplemented with 0.75% β-glucan (−1.56) (Table 3). Hue angle and L* values are well correlated depicting sample darkness with progression in supplementation levels (Cliff et al. 2007).

Effect of β-glucan addition on sensory attributes of *dahi*

Flavor

Sensory scores of *dahi* were affected by the addition of different solids level of β-glucan (Table 4). An increase in flavor scores with the increasing solids level of β-glucan up to 0.5% solids level was recorded; thereafter flavor scores decreased slightly at 0.75% followed by the lowest scores at 1% β-glucan level. The highest level i.e. 1% β-glucan received least flavor score, attributed—to the destabilization of product. The highest scores were observed at 0.5% solids level and least scores were observed at 1% level. Sample with 1% solids level exhibited statistically significant difference ($P < 0.05$) with all other groups. Similar results were observed by Kip et al. (2006), Staffolo et al. (2004), Ramanathan and Sivakumar (2013) in fortified *dahi* and yoghurt samples.

Mouthfeel

Mouthfeel scores were also affected with addition of different solids levels of β-glucan (Table 4). Addition of β-glucan increased mouthfeel of *dahi* samples up to 0.5% after that a decreasing trend was observed at higher levels. A slimy mouthfeel was observed upon β-glucan addition in *dahi*. As per Brennan and Tudorica (2008) inclusion of β-glucan in

Table 4 Effect of addition of β-glucan at different solids levels on sensory scores of dahi

Levels of β-glucan (%)	Flavor	Mouthfeel	Texture	Color and appearance	Overall acceptability
0	7.04 ± 0.15[a]	7.24 ± 0.20[a]	7.84 ± 0.19[a]	7.59 ± 0.18[a]	7.43 ± 0.17[a]
0.25	7.18 ± 0.14[a,b]	7.38 ± 0.17[a,b]	7.94 ± 0.14[a,b]	7.87 ± 0.15[a,b]	7.52 ± 0.15[a,b]
0.5	7.59 ± 0.13[b,c]	7.88 ± 0.15[c]	8.26 ± 0.13[a,b,c]	8.18 ± 0.19[b,c]	7.88 ± 0.13[b,c]
0.75	7.24 ± 0.21[a,b,c,d]	7.50 ± 0.22[a,b,c,d]	8.03 ± 0.13[a,b,c,d]	7.91 ± 0.20[a,b,c,d]	7.67 ± 0.15[a,b,c,d]
1.0	3.56 ± 0.15[e]	3.53 ± 0.12[e]	3.56 ± 0.17[e]	3.38 ± 0.22[e]	3.51 ± 0.13[e]
CD	0.445*	0.492*	0.435*	0.525*	0.412*
	0.59**	0.652**	0.577**	0.696**	0.546**

Means with the same superscript in a column are not significantly different

n = 9

* Significant at $P < 0.05$

** Significant at $P < 0.01$

yoghurt increases creaminess of the product resulting in smoother mouthfeel. Control sample significantly ($P < 0.05$) varied in mouthfeel with 0.5% β-glucan group, while sample with 1% solids level of β-glucan showed highly significant ($P < 0.01$) difference with all other groups. Similar results were observed by Kip et al. (2006) and Staffolo et al. (2004) where the authors concluded that higher fiber levels result in lower sensory scores.

Texture

Addition of β-glucan at different solids levels increased the texture score of *dahi* compared to control. The highest score were recorded for 0.5% solids level of β-glucan containing sample and least score were recorded for sample containing 1% solids level of β-glucan (Table 4). Statistically, non-significant difference was observed between control and other groups till sample containing 0.75% solids level of β-glucan. However, sample with 1% solids level of β-glucan varied significantly ($P < 0.05$) with other groups. Similar trends were reported by Brennan and Tudorica (2008), Staffolo et al. (2004) and Ramanathan and Sivakumar (2013). Fernandez-Garcia et al. (1998) reported that fiber addition to unsweetened yoghurt improved the body and texture. However, at higher level (1% β-glucan) reduced scores might have been resulted from weak gel structure of *dahi* caused by increasing fiber concentration (Vasiljevic et al. 2007). Garcia-Perez et al. (2005) reported that addition of orange fibre at 0.6 and 0.8% had a breakening effect in the gel structure of yoghurt. Brennan and Tudorica (2008) reported higher texture scores for yoghurt containing 0.5% β-glucan (4.1) than yoghurt containing 1.5% β-glucan (3.8). Bahrami et al. (2013) also observed that the texture of yoghurt improved with addition of barley β-glucan.

Color and appearance

There was significance difference ($P < 0.05$) between color and appearance scores between control and samples containing β-glucan (Table 4). No significant difference was observed between control and 0.25% β-glucan enriched samples. However, control sample was significantly different with the sample containing 0.5% solids level of β-glucan, while sample with 1% solids level of β-glucan fetched significant difference with all other groups. The highest color/appearance values were recorded for the sample with 0.5% β-glucan and least scores were recorded for 1% solids level containing sample. Increased darkness at higher levels might have resulted in lower appearance scores. As per Fernandez-Garcia and McGregor (1997), yoghurt containing two oat fibers with different insoluble dietary fiber content (88 and 97%, respectively) at 1.32% resulted in an acceptable product. Contrary to author's findings, our study indicated decreased appearance scores at 1% level due to destabilization of product (Higher syneresis).

Overall acceptability

Overall acceptability scores were calculated and received by taking average scores of all the sensory parameters (Table 4). The product was found to be acceptable till 0.75% β-glucan level and unacceptable at 1% level. Overall acceptability score of control sample was significantly ($P < 0.05$) different from sample containing 0.5% solids level of β-glucan, whereas sample containing 1% solids level showed highly significant ($P < 0.01$) difference with other samples. Maximum overall acceptability scores were observed for sample containing 0.5% solids level of β-glucan, while minimum scores were obtained for sample containing 1% solids level of β-glucan. Ramanathan and Sivakumar (2013) observed decreasing sensory scores with increasing oat concentration in yoghurt. Authors reported thatoats concentration above 2% decreased the taste, appearance, color, body and texture score and the product became less acceptable to consumer. Sample containing 0.5% solids level of β-glucan exhibited optimum instrumental color and sensory properties when compared with other samples. Hence, optimized solids level of β-glucan was chosen at 0.5% level to be added in *dahi* formulation.

Conclusion

In order to enhance the functional properties of *dahi*, β-glucan was added at variable concentrations in low fat buffalo milk to provide functionality of missing fat and to improve physical, rheological and textural properties of the final product. Among the different concentrations of β-glucan used, 0.5% level was found to be optimal with respect to syneresis and viscosity properties. Less whey separation and increased viscosity was observed upon β-glucan enrichment in *dahi*. Firmness and consistency of *dahi* increased in low fat functional *dahi* compared to control samples, but higher levels of β-glucan (>0.5%) were found to be detrimental to *dahi* quality. However, cohesiveness values of *dahi* decreased with β-glucan addition except at higher levels. The addition of 0.5% level of β-glucan also fetched significantly better instrumental color values and sensory scores with attractive or natural *dahi* color as compared to *dahi* containing other levels of β-glucan. Overall, β-glucan can be successfully used as a functional ingredient to improve the quality of low fat *dahi or similar products*.

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