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Properties of sweetened milk fortified with dietary fibers

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Abstract
Having wide-ranging beneficial effects on human health, dietary fiber (DF) has come to be recognized as an important ingredient of health foods. In the present study, 5 different mix comprising of commercially available DF sources *viz.* microcrystalline cellulose (Vitacel MCC-105), oat fiber (Vitacel HF-600), psyllium husk and inulin (Raftiline ST) were incorporated into milk (DF ranging from 1.47 to 5.7%) and their effect on the properties determining the acceptability of sweetened milk was evaluated. All the test samples showed acceptable flavor. Statistically, appearance (both unstirred/undisturbed and stirred) and consistency was highly affected by the level of DF (P, 0.022 < alpha 0.05), with change in the concentration and type of DF. Due to the increase in viscosity of milk with the addition of psyllium husk at 0.5% level, the consistency score decreased. The change in the instrumental viscosity was statistically significant (P, 6.88E-07 < alpha 0.05). The alcohol index indicating the heat stability of the milk improved enormously with the addition of DF blends (>88).

Keywords: Dietary fiber blend, inulin, microcrystalline cellulose, oat fiber, psyllium husk, viscosity, fortification

Introduction

Currently some 150 million households around the globe are engaged in milk production (FAO, 2023) [13]. According to OECD-FAO (2020), world milk production is projected to grow at 1.6% p.a. to 997 Mt by 2029. India and Pakistan are expected to account for more than 30% of world milk production in 2029. In terms of valuation, by 2026, the global dairy market is expected to grow to about 1128 billion USD from 827.4 billion USD in 2020 (Shahbandeh, 2022) [33]. By geography, Asia-Pacific region is the largest region in the dairy products market. According to the Business Research Company Press release (2023), the global dairy products market size is projected to grow from $480.52 billion in 2022 to $501.84 billion in 2023 at a compound annual growth rate (CAGR) of 4.4% and will further grow to $587.74 billion in 2027 at a CAGR of 4.0%. In India, milk production is increasing at a CAGR of 6.2% from 146.31 million tonnes (MT) in 2014-15 to 209.96 MT in 2020-21 (PIB, 2022) [28].

Keeping in view the health benefits of dietary fibers, WHO has recommended an intake of 25 g DF/day and similarly in India, National Institute of Nutrition recommends an intake of 40g DF/day for Indians (WHO, 2018 and RDA, 2009). However, due to the growing urbanization, industrialization and the availability of refined food items with most of the fiber removed, DF intake is falling and the consumption of energy-dense food is increasing. Recent reports say that incidence of lifestyle related diseases/disorders are increasing in India, for instance, some 43 lakhs lives have been lost to cancer since 2011 (Kumar, 2014) [21]; colorectal cancer is the third most common type of cancer worldwide, with almost 20,000 cases diagnosed in 2020 alone (Sung *et al.*, 2021) [35]. Also, there are increasing cases of high blood pressure and diabetes (Joshi *et al.*, 2023; Iyer, 2014) [20, 19].

Various DF have been shown in clinical studies to play an important role in reducing the risk of hyperlipidemia, heart disease, diabetes mellitus, obesity, constipation and demonstrated protective effect against mouth, throat, esophageal, colorectal and breast cancers (Ioniță-Mîndrican *et al.*, 2022; Reilly and Kirsner, 1975, Spiller, 2001, Anderson *et al.*, 2009) [18, 30, 34, 1]. Some of the soluble dietary fibers (SDF) have also shown the proven efficacy of being prebiotics including inulin.

The SDF have the ability to beneficially alter the gut microbiota and also have the potential to reduce the risk of colorectal cancer, stimulate immune response, alleviate symptoms of inflammatory bowel disease, modify serum triglycerides and cholesterol, enhance mineral absorption in the intestine and thereby reduce the risk of intestinal infectious diseases, cardiovascular disease, non-insulin dependent diabetes, obesity and osteoporosis (Tuohy *et al*., 2003; Shah, 2007) [37, 32]. It is therefore common that doctors and nutritionists advise people to increase their intake of DF by increasing the consumption of whole grains, legumes, vegetables and fruits. plasma cholesterol, improving bowel microflora and bowel function, decreasing the risks of colon and other cancers and reducing blood sugar. Hence, DF preparations have attained a great commercial significance as nutraceuticals which can have considerable functional relevance to milk products. However, often the diet is lacking fiber especially in urban areas on account of changing food habits to the Western pattern. One of the suggested ways to overcome the shortfall in dietary fiber intake is to fortify the regular diet with fiber in purified or natural form (Patel and Arora, 2005a; Arora and Patel, 2011) [25, 3]. Use of DF as a functional ingredient in certain milk products has more than one benefits. It can help prevent occurrence of various diseases such as constipation, gall bladder related disorders, colorectal adenoma (Nucci *et al*., 2021) [22] and breast cancer. Fiber fortified yoghurt/dahi, desserts etc. can serve as value-added, healthful products (Arora and Patel, 2015; Arora and Patel, 2017) [25, 11]. DF plays a vital role in counteracting some of the adverse health impacts (such as hypertension, blood cholesterol etc.) often associated with consumption of milk products, especially those rich in milk fat. In a recent review by Hu *et al.*, (2023) [16], it was concluded that DF offers protective effects against various types of malignancies, including gastrointestinal cancers (such as colorectal, gastric, and esophageal cancers) and female-specific cancers (such as breast, endometrial, and ovarian cancers), as well as pancreatic, prostate, and renal cell cancers.

Traditionally, there exists some milk-based products to which some non-dairy ingredients are added which provides some DF (Patel and Arora, 2005b) [26]. However, the major limitations of such traditional products are that the level of enrichment is insufficient to label the product as “high in fiber’. In such a scenario, DF fortification of different food products could give the consumers varied options to choose in order to reduce the risk of several metabolic disorders/diseases. Therefore, in the present study, attempts have been made to incorporate various combinations of soluble and insoluble DF available commercially to milk and to evaluate their impact on the properties of sweetened milk.

Materials and Methods

Source of Materials

Fresh, chilled, raw buffalo milk, pasteurized skim milk, skim milk powder (SMP) and sugar (ground to a fine powder using Inalsa kitchen-grinder) of commercial grade, were obtained from the Experimental Dairy, National Dairy Research Institute (NDRI), Karnal, India. Vitacel oat fiber (HF-600) and Vitacel microcrystalline cellulose (MCC-105) were procured from M/s J. Rettenmair and Sohne Gmbh, Germany. Psyllium (*Plantago ovata)* husk was sourced from ‘Sat Isabgol’, Palani Group, India. Inulin ‘Raftiline ST’ was sourced from ORAFTI, (Belgium).

Development of Dietary Fiber-Fortified Milk (DFFM)

Various soluble and insoluble fiber preparations were first hand-blended into milk along with powdered sugar and then were homogenized (at 60-65^{0}C), pasteurized ((at 75-80^{0}C), and stored in refrigerator (at 5^{0}C) undisturbed for 18 h in individual glass beakers (150 mL) with the top covered with aluminium foil. The samples were served to a panel of nine sensory judges after tempering to room temperature for 30 min. and then were also analysed for physico-chemical properties.

Sensory Score Card

Structured linear scales of 10 cm length were used for different attributes like flavour, texture and appearance (Arora, 2024a) [7]. Evaluation of the samples was carried out by a panel of 9 trained judges from the Dairy Technology Division of the Institute. The acceptability of a given characteristic was registered by making a vertical linear mark at the appropriate point along the horizontal scale line. The numerical value of the acceptability was read out on the scale at the point of the marking by measuring the linear distance from the lower extreme (1 mm being equivalent to 1-point score).

Fat and SNF analysis

The fat content of skim milk, buffalo milk or mixed milk was determined by the Gerber method as outlined in IS: 1224 (Part I) 1977. Titratable acidity was determined by the method described in IS: 1479 (Part I) 1960. The pH of the milk was determined using a digital pH meter (Thermo Orion, Model 420+). The SNF content was determined using an ISI lactometer (reading corrected for 27 °C using the standard ISI table) and the following formula:

$$\text{SNF (\%)} = \frac{\text{CLR}}{4} + 0.25\ \text{Fat (\%)} + 0.44$$

Sedimentation (mL)

Sedimentation in sweetened mixed milk added with dietary fiber was determined by a centrifugation method using a Remi centrifuge. A 10 ml sample taken in a 15 ml conical-bottom, plastic centrifuge tube was centrifuged for 15 min at speed ‘3’. After centrifugation, the supernatant was carefully decanted and the volume of the pellet was read out as sedimentation in millilitres.

pH and Viscosity

pH of the fiber-added milk was determined using a Thermo Orion pH meter. Viscosity measurement on sweetened milk added with dietary fiber (20 °C) was carried out using the Viscostar Plus L viscometer (fitted with an LCP spindle or TL-5 spindle) at a defined shear rate.

Alcohol Index

10 ml of the sample was taken into a 15 ml conical-bottom, plastic centrifuge and was centrifuged for 15 min at speed ‘3’. Five millilitres of the supernatant were taken into a series of 15 ml glass test-tubes and an equal quantity of alcohol solution (concentration ranging from 58 to 90 percent with the difference of 2 percent between two successive solutions) was added to each consecutive tube, each addition being followed by thorough mixing. The concentration of alcohol solution below the one that just caused destabilization of the milk system as evident from

the appearance of white particles or flecks on the wall of the tube, was noted as the alcohol Index of the milk added with dietary fiber and was expressed as %.

Results and Discussion

In the present study, first toned milk with 3.0% fat and 8.5% SNF was prepared by mixing of skim milk, and SMP to the fresh buffalo milk. then sweetened milk was developed with the fortification with different blends of DF. Due to the white colour, thin consistency and delicate taste of milk several DF sources were screened in the laboratory for their suitability to develop sweetened milk and then, a few of the DF source were selected (Arora, 2006) [4]. From the selected DF sources, 5 different combinations of DF blends were identified (DF content ranging from 1.47 to 5.7%) as shown in the Table 1. They comprise different percentage of psyllium, oat fiber (HF-600) and micro crystalline cellulose (MCC-105) in addition to inulin as the components of the DF blend. Table 2 shows the effect of their incorporation into milk on the sensory properties of milk. Due to the white colour, little sweet taste and very less effect on the viscosity of milk, addition of inulin @ 3.0 and 4.0% was found to pose no difficulty. However, the incorporation of DF with high content of insoluble fiber like oat fiber (HF-600) and MCC-105 was quite challenging due to their tendency to settle down and coarse mouthfeel. Also, psyllium affected the viscosity of milk tremendously. In last decade, the popularity of plant-based milk is growing; however, plant-based milk-like extracts are inferior in quality (both in taste, health and nutrition) than the natural milk (Arora, 2024a) [7]. Therefore, it is advocated that they should not be called by the term ‘milk’ (Arora, 2023a) [5].

Statistically, sedimentation rating, mouthfeel, flavor and sweetness of the sweetened milk remained unaffected with the different levels and combination of DF. Appearance (both unstirred/undisturbed and stirred) and consistency was highly affected by the level of DF; for appearance (stirred) ratings, F value was found to be 11.52 which is > F Critical 2.78 and P (0.022) < alpha (0.05), hence there was significant difference for appearance score with change in the concentration and type of DF. Sweetened milk DFM3 showed higher sensory ratings for the appearance (undisturbed as well as stirred) and overall acceptability.

Since the DF fortified milk has been developed as a healthy option for the health-conscious consumer, therefore the level of added sugar was intentionally kept at lower levels than the commercially available milk drinks in the Indian and European markets with 8% or more sugar. Though inulin is slightly sweet in taste but the sensory panelists were not able to make out the statistically significant difference among all the test samples wherein sugar was added at a constant level of 5%. Regarding flavor, all the test samples showed acceptable flavor and the samples DFM3 and DFM4 showed higher acceptability (flavor scores were close to 85). The difference being statistically non-significant. Similarly, there was non-significant difference in the samples for the attribute mouthfeel; DFM2, DFM3, DFM4 and DFM5 however showed higher acceptability than the DFM1 wherein the psyllium content was particularly high. The higher content of psyllium (0.5%) in DFM1, resulting in gelation may be the reason that the consisitency score was significantly lower than the other four samples. Previously, similar results of increase in viscosity and decrease in consistency scores were reported at 0.5% level of psyllium husk in comparison to 0.25% level by Arora (2024b). They found this reason to be behind the difficulty in swallowing and increased sliminess in the product. However, in the present study with the presence of insoluble DF such as oat fiber and microcrystalline cellulose, there was an improved acceptability at 0.27% and 0.37% psyllium husk in the sweetened milk. Further, with increase in the content of psyllium husk (DFM1), though the sedimentation rating appeared to be less sensorially affected, an increase in the sedimentation value was notice when measured using centrifuge (Table 2 and Table 3). This may be attributed to the gel forming property of the husk at high level of 0.5%, because of which less sediment was apparent to the eyes of the tester. However, the consistency score decreased due to an increase in the consistency of the product probably due to the water holding property of the psyllium husk as was also evident through the increase in apparent viscosity measured using viscosity meter. Similar increase in water holding in cake batter enriched with psyllium husk was observed by (Beikzadeh *et al.*, 2016) [12]. The psyllium husk is hydrophillic in nature due to its -OH groups and -OH of alcohols as detected by the Fourier Transform InfraRed Spectroscopy stretching vibrations at 3447 and 3207 cm^{-1}, respectively (Farahnaky *et al.*, 2010) [14].

In the samples DFM3, DFM4 and DFM5 there was less gel formation and hence an improved appearance score of the DF-fortified milk but then it had shown some settling of insoluble DF *viz*. HF-600 and MCC-105 as evident from the low scores of sedimentation rating.

The pH of the samples was near neutral and that remain unaffected with the addition of added DF blends (Table 3). The alcohol index indicating the heat stability of the milk improved enormously with the addition of DF blends (>88). All the five samples prepared with different levels of DF showed statistical difference for the parameters of instrumental sedimentation (F value is 133 and is > F Critical 3.26 and P (7.91E-10) < alpha (0.05), hence there was a significant difference between sensory score with different concentration of DF) and the instrumental viscosity (F value is 2086.79 and is > F Critical 6.39 and P (6.88E-07) < alpha (0.05), hence significant difference between sensory score with different concentration of DF).

Use of DF as a functional ingredient in certain milk products has more than one benefits. Fiber fortified yoghurt/dahi, desserts such as *kheer* (a rice-based milk dessert) etc. can serve as value-added, healthful products (Arora and Patel, 2015; Arora and Patel, 2017) [10, 11]. Hence, DF preparations have attained a great commercial significance as nutraceuticals which can have considerable functional relevance to milk products. In India, there is a growing concern for widespread prevalence of metabolic diseases and disorders related to lifestyle changes including sedentary mode of living and an increase in take of refined foods thereby resulting in reduce intake of DF. There are several reports showing an increasing trend of fortification of milk and milk products with DF in new food product development to meet the challenging health needs of the modern consumer with reduced fibre intake (Sendra, *et al*, 2008; Yadav, *et al*, 2016; Arora *et al.*, 2015; Palacio *et al*, 2018) [31, 39, 10, 24]. In this respect, selecting the developed DF blends (DFM2, DFM3, and DFM5 with corresponding DF 5.57%, 4.47% and 5.47%, respectively) will help the dairy product manufacturers offer sweetened milk with 13.36 g, 10.72 g, and 13.1 g per 240 mL serve, respectively with the claim "High in dietary fiber" (FDA, 2013) [15].

The Indian dairy is growing at a fast pace. Dairy products are rich source of protein and calcium. The increased availability of milk and milk-based products would definitely prove useful and beneficial towards an improved health and nutritional status of Indians at large (Arora, 2022) [9]. The developed DF blend with the mix of four DF sources have been analysed for its effect on protein digestibility of milk and calcium bioavailability and found to have no negative effect (Arora and Patel, 2019; Arora, 2023b) [2, 6]. The high demand for nutritious milk and milk-based products by the consumer along with the thrust coming from the Government of India to promote and support entrepreneurship into dairy requires more new products to be developed and explored. In this respect, DF fortified sweetened milk can prove as a game changer.

Table 1: Composition of Dietary Fiber Blends

Sample Code	Psyllium (P) %	HF-600%	MCC-105%	Inulin %	Sugar %	DF %
DFM1	0.50	0.36	0.84	4.00	5.00	5.7
DFM2	0.37	0.36	0.84	4.00	5.00	5.57
DFM3	0.27	0.36	0.84	3.00	5.00	4.47
DFM4	0.27	0.36	0.84	_	5.00	1.47
DFM5	0.27	0.36	0.84	4.00	5.00	5.47

Table 2: Sensory rating of homogenized DFFM

Parameter	Sample no.					F-value	P-value
	DFM1	DFM2	DFM3	DFM4	DFM5		
Sedimentation rating	87.50	85.00	69.43	67.14	69.43	ns	0.07688
Appearance (Undisturbed)	27.60	71.80	75.71	74.43	74.14	34.11	1.41E-09
Appearance (Stirred)	52.83	82.43	87.86	82.29	84.86	11.51	2.31E-05
Consistency	60.14	79.43	79.71	80.86	81.43	4.98	0.00458
Mouthfeel	72.43	89.86	89.14	88.57	87.57	ns	0.071734
Flavor	74.57	82.14	85.43	84.29	82.86	ns	0.082096
Overall acceptability**	65.53	82.20	79.93	78.61	78.5	45.58	0.001363
Overall acceptability#	71.83	84.86	82.96	80.57	81.18		
Sweetness	74.83	75.50	61.43	59.86	59.29	ns	0.052626
** =Sedimentation + Appearance (Undisturbed) + Mouthfeel + Flavour # =Sedimentation + Appearance (Stirred) + Mouthfeel + Flavour							
Means of triplicates							

Table 3: Physico-chemical Properties of homogenized DFFM

Parameter	Sample no.					F-value	P-value
	DFM1	DFM2	DFM3	DFM4	DFM5		
Instrumental sedimentation (ml)	3.5	2.5	1.50	1.75	1.25	133	7.91E-10
Instrumental viscosity (mPa.s) (LCP, 20 °C, 14.68 shear rate)	58.37	26.15	14.51	17.01	13.31	2086.78	6.88E-07
pH at 25.0±0.5 °C	6.67	6.67	6.67	6.67	6.68	ns	-
Alcohol index	>90	>90	>88	>88	>90	ns	-
Means of triplicates							

Conclusion

In the present study, different mixtures of dry dietary fibers were added to toned milk and the effect was analyzed on the sensory and physical properties of prepared DF-fortified sweetened milk. The incorporation of DF with high content of insoluble fiber such as oat fiber (HF-600) and MCC-105 was quite challenging due to their tendency to settle down and coarse mouthfeel. Also, psyllium affected the viscosity of milk tremendously. All the test samples showed acceptable flavor. Statistically, appearance (both unstirred/undisturbed and stirred) and consistency was highly affected by the level and type of DF. Sweetened milk DFM3 showed higher sensory ratings for the appearance (undisturbed as well as stirred) and overall acceptability. Due to the increase in viscosity of milk with the addition of psyllium husk at 0.5% level, the consistency score decreased. The alcohol index indicating the heat stability of the milk improved enormously with the addition of DF blends (>88). The change in the instrumental viscosity was statistically significant (P, 6.88E-07 < alpha 0.05). There was statistical difference for the parameters of instrumental sedimentation (P, 7.91E-10 < alpha, 0.05). Based on sensory and instrumental analysis, DFM3, DFM4, DFM5 and DFM2 which exhibited higher acceptability as sweetened milk than DFM1, can be selected by the dairy entrepreneurs for developing fiber-fortified milk.

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Conflict of interest statement

The authors declare that they do not have any conflict of interest.

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