

RESEARCH ARTICLE

Inulin and polydextrose as fat replacers in non-fat dahi: physicochemical, textural and sensory properties

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Abstract: The potential of inulin and polydextrose as a fat replacer in fat-free dahi was evaluated in this study. The effects of adding combination of different type of inulin with polydextrose (1:1) on the physicochemical, texture and sensory properties of non-fat dahi were investigated during storage. Compared with control non-fat dahi (CND), the addition of combination of inulin and polydextrose increased the solid content, pH, viscosity, firmness value and water holding capacity of non-fat dahi, however, no such difference was observed between control full-fat dahi (CFA) and dahi added with fat replacers. Sensory scores of dahi added with fat replacers were similar to that of CFD while lowest acceptability scores were observed for CND. The sensory attributes and physicochemical properties such as firmness, water holding capacity and pH value decreased significantly after 6 days of storage in both control dahi and dahi added with fat replacers. The results indicated that combination of inulin and polydextrose may be used as alternative sources of fat replacer to enhance the quality attributes of non-fat dahi.

Keywords: Dahi, polydextrose, Inulin, Sensory attributes, Physicochemical characteristics

Introduction

With the changing life style and dietary patterns, non-communicable diseases like obesity, cardiovascular disease and cancer have become the major health problems worldwide. The growing concern established relationship among health, diet and maintenance of healthy weight has boosted the market of foods with reduced energy value (Mahmood et al. 2024). Since fat has higher caloric density than that of most other nutrients in foods, reducing fat and cholesterol content is currently one of primary trends in food product innovation. Nowadays, the production and consumption of non- or low-fat fermented milk has increased, such that the global market of low-fat yoghurt was valued at 22.3 billion USD in 2023 and is predicted to reach 49.3 billion USD in 2032 at a CAGR of 9.1% over the forecast period (IMARC, 2023). However, elimination of fat is accompanied with some concerns related to low viscosity, poor texture and whey syneresis (Aryana and Olson, 2017).

Carbohydrate based fat substitutes have been used to partially or fully replace fat. These are fat substitutes derived from cereals, grains, and plants that include digestible and non-digestible carbohydrates. Carbohydrate-based fat-substitutes provide some of the functions of fat by binding water, and providing texture, mouth feel, and opacity. Inulin and polydextrose as a prebiotic can be used as fat replacers in low-fat dairy products because of their advantageous functionalities. Inulin, a non-digestible carbohydrate, is now employed in increasing number of applications across the food market; it can for instance be found in dairy and bakery products, in beverages, in cereals and cereal bars, in low-fat spreads, in ice cream and in confectionary products. It can form a creamy, fat-like gel when dissolved in water. Obtained gel can enhance creaminess and juiciness in various food products. This makes it an effective fat replacer that provides a fat-like mouthfeel without altering rheological properties (Nikolić et al. 2024). Polydextrose, a complex and non-digestible carbohydrate made from glucose, sorbitol and citric acid, is a water-soluble dietary fiber has some health effects due to its laxative effect and control of blood glucose and cholesterol levels (Zhu et al. 2022). Polydextrose has some technological properties in addition to its health benefits; including it forms highly viscous gel-like matrix contributing to creaminess,

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viscosity and mouthfeel (Nikolić et al. 2024). Therefore, it was used as fat replacer in low-fat dairy products. Huang et al. (2020) reported improved water holding capacity, textural and organoleptic properties of fat-free buffalo set yogurt by addition of polydextrose at a concentration of 3%. The addition of polydextrose as a fat replacer with the level of 3% to skimmed yogurt increased the viability of starters and enhanced the physical and sensory properties of the product (Hamdy et al. 2021).

Dahi has managed its popularity in Indian diet despite changing lifestyles and food habits. In dahi preparation, a part of the milk lactose is converted into lactic acid by the action of starter culture. It is consumed either in main course of meal, as a refreshing beverage or as dessert besides being used as a base for the preparation of culinary products. In India, about 7% of the total annual milk production is utilized for making dahi (Prajapati and Sreeja, 2014), and this sector is showing a growth rate of more than 20% per annum. As the liquid milk is usually converted to dahi in household conditions, it was thought appropriate to study the quality of dahi prepared using skim milk containing the carbohydrate derivatives. Accordingly, the objective of this study was to evaluate the effect of adding combinations of carbohydrate-based fat replacers on the sensory and physicochemical properties of fat free set dahi. Dahi quality indices as a function of inulin and polydextrose addition were investigated throughout the storage of 6 days at 4°C.

Materials and Methods

Raw materials and ingredients

Fresh cow milk from the Experimental dairy of ICAR-National Dairy Research Institute, Bengaluru, India was used for the preparation of skim milk and full fat milk. Two types of powdered inulin i.e., inulin frutafit TEX (IFT) (carbohydrate, $\geq 99.5\%$; inulin, $\geq 99.5\%$; fructose, glucose and sucrose, $\leq 0.5\%$; ash, $\leq 0.2\%$ on dry matter basis) and inulin frutafit HD (IFHD) (carbohydrate, $\geq 99.5\%$; inulin, $\geq 90\%$; fructose, glucose and sucrose, $\leq 10\%$; ash, 0.2% on dry matter basis) extracted from chicory roots were procured from DKSH India Pvt. Ltd., Powai, Mumbai, India. Polydextrose (Litesse® II; polydextrose, $> 90\%$; levoglucosan, $< 4.0\%$; glucose, $< 4.0\%$; sorbitol, $< 2\%$ on anhydrous, ash free basis) was procured from Danisco (India) Pvt. Ltd., Haryana, India. All the chemicals used for the preparation of different reagents were of Analytical Grade. Mixed culture (*Lactococcus lactis* ssp. *lactis*, *Lactococcus lactis* ssp. *cremoris* and *Lactococcus lactis* ssp. *lactis* var. *diacetylactis*) was obtained from Dairy Microbiology Department of the institute for the preparation of dahi.

Preparation of dahi samples

Skim milk (0.23% fat and 9.4% solids-not fat) and full fat milk (3.1% fat and 9.4% solids-not fat) was used for preparation non-fat and full fat dahi, respectively. In the preliminary trials, two variants of inulin (IFT and IFHD) and PD were used individually (2 and 3% w/w) and in combination of either of the inulin (IFT and IFHD) with polydextrose (PD) (each at 1% and 1.5% W/W, respectively) for preparation of non-fat dahi. Results indicated that combination of inulin with PD was well accepted based on sensory as well as viscosity measurements than the individually stabilized dahi. Hence, in the present study for preparation of non-fat dahi, the milk was added with IFT-PD (each 1%, w/w) and IFHD-PD (each 1%, w/w). Incorporation of fat replacers was added to non-fat milk at 50°C with very slow rate of addition and continuous stirring. They were then heated at 90°C for 10 min in a water bath, rapidly cooled to 40°C, inoculated with mixed culture at 37°C at a rate of 1%, dispensed into 100 ml polystyrene cups (for physicochemical and sensory test) and 500 ml glass beaker (for viscosity test) and incubated at 37°C for 8 h. Dahi samples were transferred carefully and kept in a refrigerator at 4°C before analyses and randomly sampled for physicochemical and sensory analysis on days 0, 2, 4 and 6, respectively. A control full-fat (CFD) and control non-fat dahi (CND) were prepared from full-fat milk and skim milk, respectively according to the described method but without addition of fat replacers.

Sensory evaluation

Sensory evaluation of dahi samples was carried out with a 15-member panel (ages 22 to 50 year) who were scientists, students and technical staff of the Institute. The panelists had a good knowledge on the sensory evaluation of dairy products and participated previously in such evaluations. Dahi samples (100 ml) in the polystyrene cups were conditioned at room temperature (30°C) for 15 min before testing. Sensory evaluation of the samples was carried out in the sensory evaluation room under appropriate fluorescent lighting. Each panelist was asked to taste the samples and rate the sensory parameters on a 9-point hedonic scale. Water was provided to rinse the palate before and after tasting the sample. According to the 9-point structured hedonic scale, the acceptance test was carried out for the attributes of color and appearance, body and texture, flavor and overall acceptability. Panelists were also requested to give the scores and comments on a sensory evaluation score card.

Physicochemical analysis of dahi samples

pH and titratable acidity

The pH values of dahi samples were measured using a digital pH meter (Cyberscan 2500, Eutech Instruments, Mumbai). Titratable acidity (expressed as % lactic acid) was determined after mixing 10 g of dahi with 20 ml of hot distilled water (60°C) and titration

with 0.1 N NaOH using phenolphthalein (0.5%) as an indicator to an end-point of faint pink color.

Viscosity

A rotational viscometer (RVDV-II Pro, Brookfield Engineering laboratory, Stoughton, MA, USA) was used to measure viscosity of dahi samples and results are expressed as centipoise (cP). 400 ml of the dahi sample set in 500 ml capacity glass beaker maintained at temperature of 30°C was used for measurement. RV4 spindle was used and readings were taken with the increasing rpm from 10 to 100.

Water holding capacity

Water holding capacity (WHC) of dahi sample was determined as per the method described by Veena et al. (2017). Ten gram of dahi sample was taken in 15 ml centrifuge tube and centrifuging it at 3000 rpm for 10 min at ambient temperature (30°C). After centrifugation, weight of clear whey separated was measured and per cent water holding capacity expressed as follows.

$$\% \text{ WHC} = \frac{\text{ND} - \text{WE}}{\text{ND}} \times 100$$

Where, ND = weight of dahi sample; WE = weight of expelled whey

Firmness

TA.XT. Plus texture analyser (Stable Micro Systems, Godalming, Surrey, UK) was used to measure the firmness of dahi samples (Veena et al. 2017). The probe height was calibrated to a distance of 50 mm, above the top of the container or the sample surface. For texture analysis, the dahi samples were prepared from 100 ml of milk in rigid polystyrene cups (100 µ thickness), the set samples were maintained at 30°C before analysis. During testing probe of 25 mm diameter was used and the sample cup was positioned centrally over the platform. The probe travelled to a distance of 10 mm into dahi samples, wherein the sample was compressed and after the force sensed by the probe, returned to their original position and generated a force-time curve. The test conditions were: distance, 10 mm; pre-test speed, 1 mm/s; test speed, 1 mm/s; post-test speed, 10.0 mm/s; trigger force, 5 g. The height of the force peak on the compression cycle was recorded as firmness value (N).

Statistical analysis

Mean values and standard deviations (SD) of triplicate determinations were reported. Analysis of variance was carried out to determine the difference among treatments means by using SPSS 16.0 software. The means comparison was performed with the Post Hoc test at $P < 0.05$.

Results and Discussion

Sensory properties

It could be observed from the data (Fig. 1) that there was no significant difference ($P < 0.05$) in colour and appearance score of all the samples. Narender Raju and Pal (2009) studied the effect of bulking agents on artificially sweetened misti dahi and they observed that there were no significant ($p > 0.05$) differences in the colour and appearance scores among the treatments. The CND had significantly lower scores for body and texture than CFD, IFT-PD and IFHD-PD due to lower solids content. However, significant difference was not observed among the CFD, IFT-PD and IFHD-PD. Guven (2005) reported that 1% concentration of inulin in low fat yoghurt showed no significant difference with respect to mouthfeel and body and texture with that of yoghurt made with whole milk. The highest flavour score ($P > 0.05$) was observed in IFHD-PD while lowest in CND sample. However, it did not differ significantly between CFD and IFHD-PD. Dahi added with fat replacers (IFT-PD and IFHD-PD) and CFD had similar scores ($P > 0.05$) for overall acceptability as compared to CND. Srisuvor et al. (2013) reported that the addition of inulin or polydextrose has potentially improved the appearance, color, texture, and overall preference while no such effect was found for flavour parameters.

Compositional analysis

The averages of total solids, fat, protein, lactose and ash contents of different dahi samples are shown in Table 1. The CND had significantly lower total solids content than CFD, IFT-PD and IFHD-PD. This difference is due to the milk base used as well as addition of fat replacers for preparation of dahi. As expected, the fat content of CFD was found to higher ($P < 0.05$) than the other treatments. The protein and lactose content of all treated dahi samples were found to be similar and did not differ significantly ($P > 0.05$). Increased moisture content, probably cause an increase in the total amount of soluble minerals (Madadlou et al. 2005), which led to increased ash content of CND in contrast with CFD. However, no significant difference in ash content was observed between CND and non-fat dahi added with fat replacers.

Physicochemical properties

The CND was shown to have greater titratable acidity and lower pH than CFD ($P < 0.05$) (Table 1). An increase in pH has been linked to an increase in the fat content reported in several other studies (Shaker et al. 2000; Bonczar et al. 2002). It is probably due to the influence of fat content on the growth and activity of lactic acid bacteria in dahi. This can cause the greater pH and lower titratable acidity of full-fat dahi as compared with reduced fat dahi. A similar pH ($P > 0.05$) of dahi supplemented with fat replacers and CFD may be explained by the addition of carbohydrate-based fat replacers such as inulin and polydextrose. Dahi added with fat replacers and CND had similar acidity values as compared to

CFD. Srisuvor *et al.* (2013) found that titratable acidity and pH values of the set-type low-fat yoghurt added with 1-3 g inulin or polydextrose/100 ml milk were not significantly different possibly due to no adverse change in activity of yoghurt starter bacteria. Guven *et al.* (2005) reported no significant effect on pH values of low-fat set-type yogurt by the addition of inulin as a fat replacer.

As expected, the firmness (N) of CND was lower ($P < 0.05$) than that of CFD (Table 1). Several researchers reported that reduction of firmness due to the reduction of fat (Sandoval-Castilla *et al.* 2004; Pereira *et al.* 2006; Aziznia *et al.* 2008). Higher total solids and greater interaction of fat globules with gel network in CFD are the reasons for the greater firmness. By the addition of fat replacers in the mix, its firmness was increased ($P < 0.05$) significantly compared to CND. Dahi supplemented with IFHD-PD had slightly higher ($P > 0.05$) firmness than IFT-PD but they had very similar ($P > 0.05$) firmness as that of CFD. Addition of polydextrose (1.5, 3 and 5%) (Huang *et al.* 2020) and inulin (Helal *et al.* 2018) had significant positive impact ($P < 0.05$) on textural properties compared to the control fat free or low-fat yoghurt. Paseephol *et al.* (2008) interpreted the effect of inulin addition on firmness as an indication of the interference of inulin with the protein matrix formation due to the dispersion of inulin molecules among casein micelles. They suggested that this effect can be similar to the interference of fat globules on protein matrix formation.

Highest WHC (%) was observed in CFD than CND which might be due to higher solids content and positive interaction of fat content with gel network. Addition of fat replacers (IFT-PD and IFHD-PD) significantly improves the WHC of supplemented dahi samples compared to CND while similar WHC (%) that of CFD (Table 1). Similar result was reported by Srisuvor *et al.* (2013) who stated that the addition of inulin or polydextrose has increased the WHC percentage of low-fat yogurt produced from reconstituted milk. Additionally, WHC percentage of fat free buffalo set yogurt with polydextrose at concentrations of 1.5 to

5.0% was significantly higher than the control yogurt because polydextrose has potential capability to bind water (Huang *et al.* 2020).

Addition of fat replacers (IFT-PD and IFHD-PD) slightly increase ($P > 0.05$) the viscosity of the dahi samples compared to CND and CFD, however, difference was not significant among all the samples (Table 1). Kip *et al.* (2006) found that the addition of inulin with different chain lengths at different concentrations (1.55, 3 and 4%) to low fat yoghurts increased the apparent viscosity and the increase was higher when long chain inulin was used.

Storage stability of dahi

Dahi samples were evaluated for sensory and physico-chemical properties during 6 days of storage. Figure 2 shows the sensory analysis results of dahi samples during storage period. Colour and appearance scores neither differed significantly among the treated samples nor during the storage at 5°C. The colour and appearance score for CFD was found to be slightly lower than ($P > 0.05$) other treated samples throughout the storage period, however, significant difference was not observed up to 4th day of storage. This might be due to the yellow creamy layer on the surface of CFD contains 3% fat. Body and texture score of CND was lower than the other treated samples. The scores of dahi samples containing fat replacers were similar to that of CFD throughout storage. The scores increased during storage marginally in all the samples up to 4th day of storage and later declined significantly ($P < 0.05$) on the 6th day of storage. Aggregation of inulin crystals took place in the continuous phase, thereby increasing the effective fraction volume, which could explain the important rheological and sensory changes, observed in low-fat dairy dessert with long-chain inulin (Torres *et al.* 2010). The CND had lower flavour score compared to other treatments throughout storage. However, significant difference was not observed between CFD and samples added with fat replacers (IFT-PD and IFHD-PD). The flavour scores decreased slightly

Table 1. Compositional and Physicochemical properties of dahi added with carbohydrate-based fat replacers

Sample	CND	IFT-PD	IFHD-PD	CFD
TS (%)	9.62±0.04 ^a	11.67±0.04 ^b	11.79±0.06 ^b	11.83±0.07 ^b
Fat (%)	0.58±0.03 ^b	0.55±0.04 ^{ab}	0.49±0.03 ^a	3.13±0.03 ^c
Protein (%)	3.15±0.08 ^a	3.36±0.13 ^a	3.29±0.11 ^a	3.34±0.15 ^a
Lactose (%)	4.18±0.07 ^a	4.15±0.03 ^a	4.15±0.06 ^a	4.17±0.06 ^a
Ash (%)	0.71±0.06 ^b	0.714±0.06 ^b	0.713±0.05 ^b	0.689±0.05 ^a
pH	4.26±0.03 ^a	4.38±0.02 ^b	4.37±0.05 ^b	4.42±0.03 ^b
Acidity (%LA)	0.728±0.03 ^b	0.708±0.06 ^b	0.718±0.04 ^b	0.694±0.03 ^a
Firmness (g)	48.03±4.25 ^a	53.10±1.37 ^b	57.06±0.75 ^b	62.1±1.11 ^b
WHC (%)	38.12±1.15 ^a	44.78±0.63 ^b	43.5±1.06 ^b	47.18±1.6 ^b
Viscosity (cP)	7580±202.5 ^a	8710±261.1 ^a	9960±589.7 ^a	8480±550.9 ^a

Data are presented as Mean ± SD. Means in each row with different superscript letters (a, b, c) differ significantly ($P < 0.05$) from each other.

Fig 1. Sensory analysis of dahi added with carbohydrate-based fat replacers. (Mean values with different letters (a–c) in the bar graph for each attribute differ significantly ($P < 0.05$); error bar indicates SD of means).

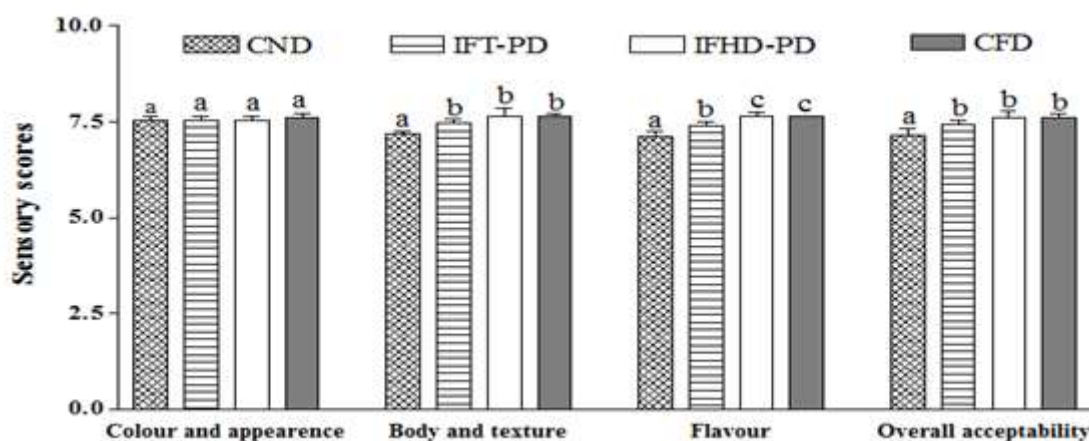
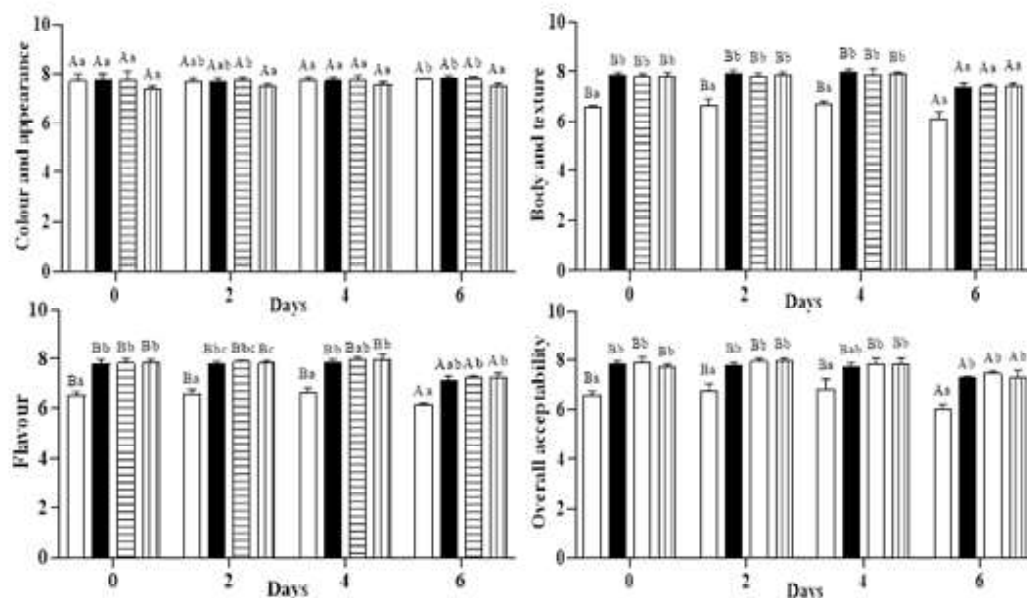


Fig 2. Sensory attributes of dahi added with carbohydrate-based fat replacers during storage period. Error bar indicates SD of mean. ^{a-c}: Indicate difference ($P < 0.05$) in dahi samples added with fat replacers, evaluated at the same time. ^{A-C}: Indicate difference ($P < 0.05$) between same samples evaluated at different storage times.

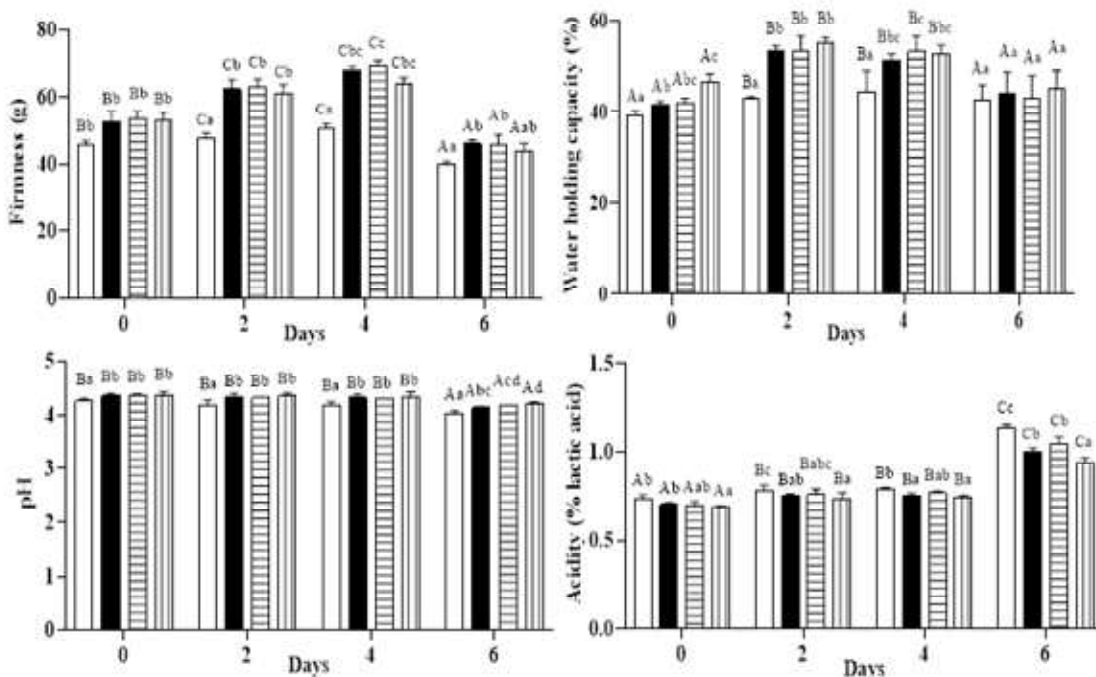


($P > 0.05$) with increasing storage period in all the samples but significant decline was observed after 6 days of storage which might be due to increased acidity and microbial activity. The overall acceptability scores of dahi with IFT-PD or IFHD-PD were significantly higher ($P < 0.05$) than CND but similar acceptance as that of CFD. The scores decreased slightly ($P > 0.05$) with increasing storage period in all the treatments but significant decline was observed after 6 days of storage. This observation could be attributed to the higher acidity and lower WHC (%) at 6th day of storage. In agreement with this finding, Huang et al (2020) who reported that total acceptability score of yoghurt with 3% polydextrose and control samples were gradually decreased during 21 days of cold storage.

Figure 3 shows the results of physicochemical analysis of dahi samples during storage period. The IFT-PD and IFHD-PD had

similar firmness value ($P > 0.05$) as that of CFD and significantly higher than that of CND during storage. The firmness increased with increasing storage period in all the treatments till 4th day and then decline after 6th day of storage (Fig 3). With respect to the WHC (%), dahi with IFT-PD or IFHD-PD had significantly ($P < 0.05$) higher WHC during storage compared to that of CND, and lower than ($P > 0.05$) that of CFD. However, no significant difference was observed between the CFD and dahi samples stabilized with fat replacers. The WHC (%) increased with increasing storage period in all the treatments till 4th day and then decline after 6th day of storage (Fig 3). These results are in agreement with those of Huang et al. (2020) who reported significant ($P < 0.05$) decrease in the WHC values during the cold storage period (21 days) for control full fat or fat-free buffalo set yogurt and yogurt with 3% polydextrose. The decreased firmness and WHC (%) could be attributed to the higher acidity and may be a bit of hydrolysis of

Fig 3. Physicochemical properties of dahi added with carbohydrate-based fat replacers during storage period. Error bar indicates SD of mean. ^{a-c}: Indicate difference ($P < 0.05$) in dahi samples added with fat replacers, evaluated at the same time. ^{A-C}: Indicate difference ($P < 0.05$) between same samples evaluated at different storage times.



protein during the storage which led to weak gel network and increase the serum loss from the gel matrix (Huang et al. 2020). As it can be seen from data presented in Figure 3, the pH values were decreased during the storage period for all treatments. However, the pH values decreased significantly ($P < 0.05$) after 4th day of storage. These results are in agreement with those of Helal et al. (2018) who reported a significant decrease in pH values during the storage of low-fat yogurt with different concentration of inulin. CND had showed significantly the lowest pH values during the storage period compared to those of CFD and dahi with IFT-PD or IFHD-PD. Acidity values were increased significantly ($P < 0.05$) during the storage period for all treatments. CND had showed significantly the highest acidity values during the storage period compared to those of CFD and dahi with IFT-PD or IFHD-PD.

Conclusions

The addition of combination of different type of inulin with polydextrose (1:1) improves the physicochemical and sensory properties of non-fat dahi. Compared to non-fat dahi, dahi supplemented with IFT-PD or IFHD-PD had higher scores for flavour, body and texture and overall acceptability. The total solids, firmness, viscosity and water holding capacity of non-fat dahi supplemented with IFT-PD or IFHD-PD were similar to that of CFD. During storage the sensory attributes and physicochemical properties decreased significantly after 6 days of storage in both control dahi and dahi added with fat replacers. Addition of non-fat dahi with polydextrose and inulin seems to be a good alternative for obtaining a functional dairy product with desired textural properties.

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