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Utilization of Inulin as a Fat Replacer in the Development of Low-Fat Yogurt

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ABSTRACT

Background: Yogurt is now recognized for its broader nutraceutical potential in promoting health and managing various conditions. This work aims to develop inulin-enriched low-fat yogurt using *Streptococcus thermophilus*, optimize inulin levels for improved texture, and assess physicochemical and sensory properties. **Methods:** This study formulated low-fat yogurt using inulin as a fat replacer and assessed its effects at varying concentrations on yogurt quality. T0 served as the control (3.5% milk fat, no inulin), while T1–T3 were treatments prepared with 0.2% milk fat and fortified with 1%, 2%, and 3% inulin, respectively, along with corresponding levels of skim-milk powder. Skim-milk powder was incorporated to standardize total solids across all samples. Key parameters, including sensory attributes, titratable acidity, pH, and, chemical compositions were analyzed, following standard procedures. **Results:** T_2 exhibited the highest moisture content (86.74%) and it remained higher than the control sample, while T_3 showed the lowest (86.58%). Ash content was notably higher in the experimental yogurts, with T_1 showing the highest value at 1.02%, followed by T_2 (0.95%) and T_3 (0.87%). Protein content was also greater in the experimental yogurts, with T_1 showing the highest protein level (4.49%), followed by T_3 (3.95%) and T_2 (3.94%). The addition of inulin had minimal influence on pH and acidity during storage. Sensory evaluation revealed no significant differences in aroma, taste, or overall acceptability between treatments. Moreover, the control yogurt was rated highest in color, appearance, and aroma, while both the control and T_3 received the highest taste scores. T_3 achieved the highest overall acceptability (7.5), but T_1 offered the best cost-benefit balance with comparable quality to the control. **Conclusion:** Finally, inulin proved to be an effective fat replacer in low-fat yogurt, with T_1 offering the best cost-quality balance and T_3 achieving the highest overall acceptability.

Introduction

Yogurt, initially valued mainly for calcium, is now recognized for its broader nutraceutical potential in promoting health and managing various conditions. Consumption of yogurt and other fermented products is associated with improved health outcomes (Savaiano and Hutkins, 2021). As a fermented dairy product containing live microorganisms, yogurt benefits immune

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function and overall health. Nutritionally, it is similar to milk but has reduced lactose (Kober *et al.*, 2007), making it more tolerated by lactose-intolerant individuals (Chowdhury *et al.*, 2024). It is rich in essential nutrients such as high-quality protein, calcium, phosphorus, B vitamins, magnesium, and zinc, contributing to immune support and improved dietary quality (Kebary *et al.*, 2004, McKinley, 2005). Low-fat yogurt, in particular, provides substantial nutrients relative to its caloric and fat content. Dietary fats are necessary for normal physiological processes, but excessive intake raises chronic disease risk, whereas moderate levels are beneficial (Siraj *et al.*, 2015).

Milk fat significantly affects the texture, flavor, and appearance of dairy products. Yogurt loses its original texture and viscosity if the fat content is lower than normal (Nikitina *et al.*, 2019). Fat replacers are substances designed to replicate the sensory and physical attributes of traditional fats in food products, offering similar qualities with significantly reduced caloric content (Nath *et al.*, 2025). Public health concerns linking animal fat to cardiovascular disease have fueled interest in low-fat dairy (Haque and Ji, 2003).

Fat replacers, which reduce the caloric content of foods, can address various physical and sensory challenges associated with low-fat formulations in final products. Furthermore, carbohydrate-based fat substitutes like inulin are particularly effective in yogurt, enhancing functionality by increasing water binding and viscosity (Żbikowska *et al.*, 2020a). Inulin, along with other carbohydrate-based fat substitutes like starches and gums, can bind water, impart a creamy mouthfeel, and mimic the sensory attributes of fat (Yousefi *et al.*, 2018). Fermentation improves the bioavailability of nutrients by breaking down complex molecules into simpler forms, facilitating better absorption of minerals like calcium and magnesium (Sawant *et al.*, 2025). Inulin fermentation in the colon predominantly yields acetate, with smaller amounts of propionate and butyrate produced. These SCFAs are then absorbed by colonocytes, with butyrate being the primary energy source (Boets *et al.*, 2015). Inulin appears especially effective for substituting fat in low-fat dairy products, as it helps enhance the product’s texture and overall mouthfeel (Ren *et al.*, 2020).

Inulin, a soluble prebiotic fiber, has been widely investigated as a functional adjunct in yogurt manufacture. Evidence shows that moderate inclusion levels (typically 1-4% w/w) improve viscosity, water-holding capacity, and creaminess, thereby compensating for fat reduction, while simultaneously reducing syneresis and supporting probiotic viability (Żbikowska *et al.*, 2020b). The functional outcomes vary depending on the botanical source and degree of polymerization; for instance, inulin extracted from chicory and globe artichoke demonstrates comparable performance to commercial preparations in pilot-scale studies (El-Kholy *et al.*, 2023). Although industrial application requires further scale-up validation, cost–benefit evaluation, storage stability studies, and regulatory consideration, current evidence strongly supports inulin’s role as a multifunctional additive capable of enhancing both the nutritional and sensory quality of health-oriented and low-fat yogurts (Kip *et al.*, 2006).

Local studies on low-fat yogurt are limited. Therefore, this work aims to develop inulin-enriched low-fat yogurt using *Streptococcus thermophilus*, optimize inulin levels for improved texture, and assess physicochemical and sensory properties. The findings may promote low-fat yogurt consumption, stimulate fermented dairy production, enhance public health, and support economic growth.

Materials and Methods

Statement of the experiment

The research was carried out at the Department of Dairy and Poultry Science (DDPS) at Chattogram Veterinary and Animal Sciences University (CVASU), focusing on the development of low-fat yogurt by employing inulin as a fat replacer and utilizing *Streptococcus thermophilus* cultures obtained from a preserved stock solution, which had been previously isolated by the supervisor's research group from locally sourced

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yogurt (Amin *et al.*, 2022). The analytical assessments were conducted at the Poultry Research and Training Center (PRTC) and the DDPS laboratories of CVASU between July and November 2021.

Development of low-fat yogurt using fat replacer (inulin)

Preparation of streptococcus thermophilus culture: For making yogurt with superior probiotic capabilities, *Streptococcus thermophilus* is a useful seed (Bari *et al.*, 2016). *Streptococcus thermophilus* cultures were reactivated from frozen stock (comprising 300 µl of 50% glycerol mixed with 700 µl of Brain Heart Infusion-BHI broth) by plating onto blood agar (Amin *et al.*, 2022). The plates were incubated at 37 °C for 24 hours, following which bacterial growth was assessed. A single colony was subsequently transferred to 10 ml of BHI broth and incubated at 37 °C for 24 hours to achieve a bacterial concentration nearing 10^6 CFU/ml, which is appropriate for susceptibility testing.

Preparation of mother culture: The *Streptococcus thermophilus* cultures cultivated in BHI broth were subjected to centrifugation at 4000 rpm for 5 minutes to collect the bacterial pellets. The supernatant was carefully discarded using a pipette, and the bacterial pellets were washed twice with sterile phosphate-buffered saline (PBS) to remove any residual broth. Subsequently, the pellets were resuspended in 2 ml of PBS. A 200 µl aliquot from this suspension, containing $5x10^8$ CFU/ml, was then introduced into 10 ml of heat-treated milk and incubated at 37 °C for 18 hours.

Preparation of low-fat yogurt using inulin: Fresh whole raw cow's milk was employed for the production of yogurt. Following collection, the milk was filtered to eliminate any extraneous particles. Skim milk was prepared by separating the cream from the raw whole milk using a cream separator at a temperature of 40 °C.

In the present study, 4 distinct formulations were developed, including a control group (T0) containing 3.5% milk fat without inulin addition, alongside three treatment groups (T1, T2, and T3) formulated with reduced milk fat (0.2%) and fortified with 1%, 2%, and 3% inulin, respectively, in combination with different proportions of skim-milk powder (SMP) (**Table 1**). Following the blending of milk with inulin percent (w/v) and SMP percent (w/v) in different ratios, the mixtures were homogenized separately using a blender until all components were fully dissolved. The homogenized mixtures were subsequently boiled, cooled to 47 °C, inoculated with 2% *Streptococcus thermophilus* culture, distributed into plastic cups, and incubated at 37 °C. Upon completion of the incubation period, all samples were allowed to rest at room temperature (21 °C) for 30 minutes before being placed in refrigeration. The prepared yogurt samples were stored at 4 °C for 7 days and analyzed after 1 and 7 days of storage.

Table 1. Experimental design (preparation of yogurt).

Sample	Milk fat (%)	Inulin (%)	Skim-milk powder (%)
Control (T_0)	3.5	0	1.9
T_1	0.2	1	4.2
T_2	0.2	2	3.2
T_3	0.2	3	2.2

Physicochemical analysis of developed yogurt

The yogurt produced was evaluated for pH, titratable acidity, moisture content, ash, and protein levels. All measurements were conducted in triplicate, with results presented as averages. The pH and titratable acidity assessments were performed on days 1 and 7. The titratable acidity was determined in triplicate using standard method ISO/TS 11869:2012 (IDF/RM 150:2012) (Mbye *et al.*, 2020). The pH of the yogurt samples was measured using a digital microprocessor pH meter (pHepÒ3, Hanna Instruments, USA), which was calibrated using buffer solutions with reference pH values of 4.0 and 7.0. Additionally, proximate analysis was conducted on the yogurt samples to determine moisture content, crude protein (CP%), and ash content (Association of official analytical chemists, 2019).

Sensory evaluation of developed yogurt

The sensory attributes of the prepared yogurt samples were evaluated by a panel of experts, with the test focused on assessing product quality (Shekhar *et al.*, 2012). The sensory analysis was conducted using a panel of judges who rated the yogurt based on a "9-point hedonic scale," where 1 to 9 corresponded to the following: dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like very much, and like extremely, respectively.

Cost-benefit analysis

The production cost analysis for low-fat yogurt encompassed expenses related to skim milk, a fat substitute (inulin), SMP, and additional relevant ingredients. The cost of skim milk was derived from the selling price of raw fresh whole milk as marketed by the supplier, while the expenses for inulin and SMP were determined according to their respective purchase prices.

Benefit-Cost Ratio = ∑ Present Value of all the expected Benefits / ∑ Present Value of all the associate costs.

Data analysis

All data were compiled and recorded in a Microsoft Excel 2010 spreadsheet for statistical evaluation. The collected data were then analyzed using STATA 13 (StataCorp IP Lakeway Drive, USA). A one-way ANOVA was conducted to assess the significance of differences among the yogurt samples, with a significance level set at $p \leq 0.05$.

Results

Sensory evaluation of developed yogurt

The control samples achieved the highest average of overall acceptability score of 8.1, followed by T_3 with a score of 7.5 and T_1 with 7.3, whereas the lowest score of 7.1 was recorded for treatment T_2 (**Table 2**). The highest sensory scores were recorded in the control samples.

Table 2. Sensory evaluation scores of developed yogurts.

Yogurt samples	Color and appearance	Aroma	Taste	Body and texture	Overall acceptability
Control (T_0)	8.2	8.4	7.6	8	8.1
T_1	7.8	7	7.2	7.2	7.3
T_2	7.8	7	7	6.6	7.1
T_3	7.8	7.2	7.6	7.4	7.5
p	0.4182	0.06	0.899	0.338	0.242

***Control**: Milk (3.5% fat) + 0% Inulin + 1.9% (w/v) Skim-milk powder, **T₁**:1 Liter skim milk + 1% (w/v) Inulin + 4.2% (w/v) skim-milk powder, **T₂**: 1 Liter skim milk + 2% Inulin + 3.2% (w/v) skim-milk powder, **T₃**: 1 Liter skim milk + 3%(w/v) Inulin + 2.2% (w/v) skim-milk powder.*

Physicochemical analysis of developed low-fat yogurt

The yogurt samples prepared were assessed for titratable acidity, pH, moisture content, ash, and protein levels. All measurements were performed in triplicate, with the results reported as averages. The assessments of pH and titratable acidity were conducted on days 1 and 7.

Titratable acidity

The acidity measurements for the control, T_1, T_2, and T_3 samples on day 1 were recorded as 0.85, 0.85, 0.91, and 0.92, respectively. In contrast, the values on day 7 were 1.03, 1.07, 1.13, and 1.11, respectively (**Figure 1**). An increase in acidity was observed throughout storage.

pH

The figure demonstrates that the average pH levels on day 1 were recorded as 4.61, 4.59, 4.50, and 4.53, respectively, while the values observed on day 7 were 4.42, 4.42, 4.42, and 4.38, respectively (**Figure 2**).

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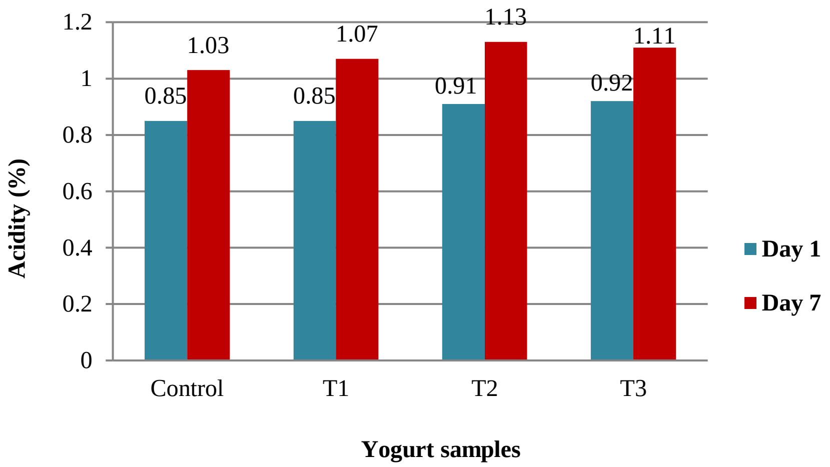

Figure 1. Acidity (%) of the yogurt samples on days 1 and 7.

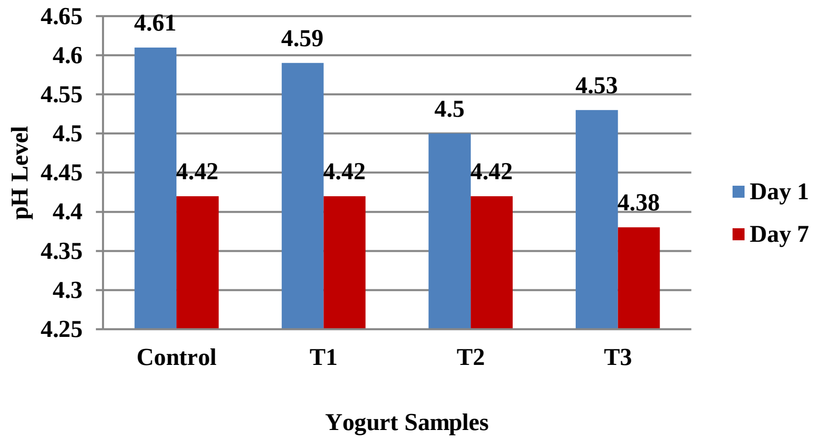

Figure 2. pH measurements of the yogurt samples on days 1 and 7.

Chemical composition

The developed yogurt samples were evaluated for moisture, ash, and protein content (**Table 3**).

Table 3. Chemical composition of developed yogurt.

Yogurt samples	Moisture(%)	Ash (%)	Protein (%)
Control (T_0)	86.63	0.83	3.42
T_1	86.63	1.02	4.49
T_2	86.74	0.95	3.94
T_3	86.58	0.87	3.95
P-value	0.002	<0.001	<0.001

Control: *Milk (3.5% fat) + 0% Inulin + 1.9% (w/v) skim-milk powder,* ***T_1****:1 Liter skim milk + 1% (w/v) Inulin + 4.2% (w/v) skim-milk powder,* ***T_2****: 1 Liter skim milk + 2% Inulin + 3.2% (w/v) skim-milk powder,* ***T_3****: 1 Liter skim milk + 3%(w/v) Inulin + 2.2% (w/v) skim-milk powder.*

The moisture content remained relatively stable among all yogurt samples, ranging from 86.58% to 86.74%, indicating a notable variation. However, significant differences were observed in ash and protein content. The control sample showed the lowest ash (0.83%) and protein (3.42%) levels, while the T_1 sample had the highest ash (1.02%) and protein (4.49%) content. These differences were statistically significant (P<0.001).

Cost-benefit analysis

In the cost-benefit analysis, the T_1 sample group exhibited the highest benefit-cost ratio of 0.77, while the T_3 sample group displayed the lowest benefit-cost ratio of 0.09 (**Table 4**).

Discussion

Development of low-fat yogurt using fat

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replacer (inulin)

In this study, yogurt was prepared using heat-treated skim milk (0.2% fat), along with inulin, SMP, and a 2% starter culture. The yogurt industry typically employs heat treatments such as heating at 85°C for 30 minutes or at 90-95 ºC for 5 minutes (Tamime and Robinson, 1985); however, the authors of this study utilized a traditional boiling method for milk preparation. Heat treatment can influence both the sensory and morphological qualities of yogurt. Among various heating methods, boiling milk resulted in the least syneresis of whey in the yogurt (Shekhar *et al.*, 2012). The study indicated that yogurt made from boiled milk demonstrated superior firmness, consistency, and viscosity index. Furthermore, high-temperature treatment of milk enhances gel firmness and minimizes syneresis in the final product (Vasbinder *et al.*, 2004). It was also observed that the rate of acid production in a mixed culture exceeds that of a single strain (Soundharrajan *et al.*, 2023). Notably, yogurt preparation in this study did not incorporate sugar, artificial flavorings, colorings, thickening agents, chemical preservatives, or stabilizers.

Table 4. Cost-benefit analysis of developed low-fat yogurts

Cost-benefit analysis (BDT)	T_1	T_2	T_3
Total cost per kg of yogurt production	169.8	222.8	275.8
Price of low-fat yogurt in Market	300	300	300
Benefit	130.2	77.2	24.2
Benefit cost ratio	0.77	0.37	0.09

***T1**: 1 L skim milk supplemented with 1% (w/v) inulin (10g) and 4.2% (w/v) skim-milk powder (42g). **T2**: 1 L skim-milk supplemented with 2% (w/v) inulin (20g) and 3.2% (w/v) skim-milk powder (32g). **T3**: 1 L skim milk supplemented with 3% (w/v) inulin (30g) and 2.2% (w/v) skim-milk powder (22g).*

Sensory evaluation of developed yogurt

No significant differences were observed in the sensory attributes (color, aroma, taste, body, and texture) of the yogurt samples during storage or between the treatments. These results are consistent with the findings of (Mazloomi *et al.*, 2011), who also reported that inulin did not have a significant impact on sensory characteristics of yogurt. In this experimental yogurt, various sensory attributes, including color and appearance, taste, aroma, body and texture, and overall acceptability, were evaluated by a panel of experts, as described by a study (Shekhar *et al.*, 2012). In the sensory evaluation, the control group scored highest in color and appearance, taste, aroma, body and texture, and overall acceptability compared to the developed yogurt samples. Among the three developed groups, the T_3 sample showed superior aroma, taste, body and texture, and overall acceptability compared to the other two groups. The higher inulin content (3%) in the T_3 sample may have enhanced the yogurt's palatability, aroma, and flavor, thereby improving consumer acceptability. Scientists also reported that yogurt containing 1.5% inulin had superior body and texture compared to control samples (Aryana *et al.*, 2007). The color and appearance of the developed yogurt samples were not affected by the treatments. Panelists preferred the low-fat yogurt samples developed using a 3% fat replacer (inulin).

Physicochemical analysis

Acidity: The replacement of milk fat with inulin led to a significant increase in titratable acidity (**Figure 1**). This outcome may be attributed to the prebiotic effects of inulin, which promote the growth of lactic acid bacteria and enhance their capacity to hydrolyze lactose (Kebary *et al.*, 2004). This study found that the addition of 1%, 2%, and 3% inulin to yogurt slightly impacted its acidity during storage. These results differ from a previous study (Guven *et al.*, 2005), which reported that inulin did not significantly influence yogurt acidity. However, the titratable acidity results from the experiments align with those reported in another study (Vijayendra and Gupta, 2012). Researchers have noted that the most desirable yogurt has a titratable acidity ranging from 0.74% to 0.83% after cold storage, increasing to 0.91% to 0.93% during storage (Aryana and Olson, 2017). It is well known that lactic acid bacteria convert lactose into lactic acid during fermentation, which contributes to extended shelf life, enhanced

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microbial safety, improved texture, and a desirable sensory profile in yogurt (Leroy and De Vuyst, 2004).

PH: In this study, the addition of 1%, 2%, and 3% inulin to yogurt only slightly affected its pH during storage. These findings differ from those reported by (Guven *et al.*, 2005), who found that inulin had no significant impact on yogurt pH. The data clearly show variation in pH across different yogurt samples, which may be due to the timing of pH measurements, as they were taken at different intervals, specifically on day 1 and day 7. An increased pH suggests greater alkalinity in the sample, while a decrease indicates heightened acidity. A pH below 7 signifies increased acidity, whereas a pH above 7 reflects a more alkaline nature. Higher bacterial activity-producing acid could lead to greater acidity, whereas lower bacterial acid production may result in reduced acidity. Over time, the pH values of the yogurt samples decreased, which can be attributed to the microbial cultures' metabolism of lactose, resulting in the production of lactic acid, formic acid, and small amounts of CO_2 (Panesar, 2011).

Chemical composition (moisture, protein and ash) of developed yogurt

The chemical composition of the various yogurt samples developed in this study showed significant variation, as indicated by data (**Table 3**). Notable differences were observed in moisture, protein, and ash contents across the samples. The addition of SMP resulted in increased total protein and ash values. T_1 sample, in particular, demonstrated a significant improvement in ash and protein levels compared to the other samples. The lower moisture content and the composition of ingredients likely contributed to the enhanced nutrient profile of T_1 yogurt.

Cost-benefit analysis

In the current study, yogurt containing 1% inulin demonstrated a higher benefit-cost ratio compared to the other two sample groups. Conversely, yogurt with 3% inulin exhibited a lower benefit-cost ratio. This discrepancy can be attributed to the higher cost associated with procuring small quantities of inulin and SMP compared to bulk purchases. It would be more economically advantageous to procure inulin and SMP in larger quantities. Additionally, purchasing milk in larger volumes and processing a significant amount of skim milk through a cream separator would result in a reduced average cost for skim milk.

Advantages and limitations of the study

This study highlights the potential of inulin as a natural fat replacer in yogurt, demonstrating its ability to improve nutritional composition while maintaining desirable sensory qualities. Additionally, it offers practical insights into developing cost-effective, low-fat dairy products without compromising consumer acceptability. A primary limitation is the restricted sample size and evaluation using a single starter strain, which may limit the generalizability of the results.

Conclusions

The development of low-fat yogurt utilizing *Streptococcus thermophilus* and inulin as a fat substitute has proven to be effective. In this investigation, inulin was incorporated into milk containing 0.2% fat at concentrations of 1%, 2%, and 3%, with the outcomes evaluated against a control yogurt produced from whole milk. The total solids content was adjusted through the incorporation of skim-milk powder. The study measured chemical composition, pH, and acidity after 1 and 7 days. Yogurt with 1% inulin exhibited the highest ash (1.02%) and protein (4.49%) content, though it had slightly lower sensory scores relative to the control. Conversely, yogurt with 3% inulin demonstrated organoleptic properties similar to those of the control. The yogurt containing 1% inulin provided the most favorable cost-benefit ratio and enhanced nutritional value, while the 3% inulin variant was superior in taste. It is recommended that further research be conducted to optimize inulin concentration, balancing sensory qualities and nutritional benefits, to enhance consumer acceptance and marketability of low-fat yogurt products. Additionally, exploring the potential of other fat replacers alongside inulin may yield further improvements in yogurt formulation.

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Authors' contributions

Bhowmik JC, Amin US and Kober AKMH contributed to the study conception and design; Bhowmik JC, Chowdhury MR, and Hossain T, conducted research; Amin US, Chowdhury MR, Hossain T, and Nakib TM prepared the draft manuscript; Kober AKMH finalized the draft. All authors reviewed and approved the final manuscript.

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Conflict of interest

The authors declared no conflicts of interest.

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