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Potential of Beneng Taro (*Xanthosoma undipes*) Fructooligosaccharides (FOS) in Enhancing Total Count of Lactic Acid Bacteria in Synbiotic Yogurt

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ABSTRACT

Synbiotic dairy products combine probiotics and prebiotics to deliver synergistic health benefits, including improved gut microbiota modulation, immune support, and enhanced functional quality. Fructooligosaccharides (FOS) are recognized prebiotic compounds that selectively promote the growth of lactic acid bacteria (LAB), strengthening the probiotic effect. However, commercial FOS sources such as chicory and Jerusalem artichoke remain costly and largely imported, limiting access for small-scale food producers in developing regions. This study aimed to evaluate the potential of Beneng taro (Xanthosoma undipes K. Koch), an underutilized Indonesian tuber, as a local FOS source to enhance LAB viability in synbiotic yogurt. FOS were extracted via enzymatic hydrolysis and incorporated into milk at 1–3% (w/v). LAB counts, pH, and sensory characteristics were evaluated. The 2% FOS addition significantly increased LAB viability (8.46 ± 0.02 log CFU/mL) compared to control (7.86 ± 0.05 log CFU/mL) ($p < 0.05$). Furthermore, the FOS-enriched yogurt demonstrated improved texture, reduced syneresis, and enhanced consumer acceptability. These findings highlight Beneng taro as a promising, sustainable source of prebiotic carbohydrates that can contribute to Indonesia's bioresource valorization and local circular food economy.

Keywords: Beneng taro; Fructooligosaccharides; Prebiotics; Synbiotic yogurt; Lactic acid bacteria

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INTRODUCTION

The global food sector is experiencing a major transition toward the production of functional foods that extend beyond conventional nutrition to deliver measurable physiological benefits. Among these innovations, synbiotic formulation have gained remarkable scientific and commercial attention due to their synergistic effects on gut health, metabolic regulation, and immune modulation (Carlson et al., 2018)(Ramin et al., 2020). Synbiotic foods are products that combine probiotics and prebiotics. Probiotics such as *Lactobacillus* and *Bifidobacterium* species enhance gastrointestinal balance through competitive exclusion of pathogens and modulation of host immune responses, while prebiotics serve as selectively fermented substrates that stimulate the growth and activity of these beneficial microorganisms (Holscher, 2021). The combination of both components forms the conceptual basis of synbiotic food systems, which represent a rapidly growing segment within the global dairy and nutraceutical markets. The demand for synbiotic and probiotic dairy products has risen substantially worldwide. The global yogurt market alone is projected to reach approximately USD 110–144 billion by 2030, driven by increased consumer awareness of gut health, high-protein diets, and clean-label formulations. In Indonesia, policy initiatives promoting school-based nutrition and milk consumption are expected to elevate dairy intake from a low per capita base, fostering greater acceptance of fermented dairy products such as yogurt. This trend is aligned with a broader shift in Southeast Asia toward functional, nutrient-dense foods designed to support preventive health and microbiome diversity.

Prebiotics encompass a wide range of non-digestible carbohydrates that beneficially influence host health through selective fermentation by gut microbiota. The major prebiotic classes include galacto-oligosaccharides (GOS), inulin-type fructans (including inulin and short-chain fructooligosaccharides/FOS), isomalto-oligosaccharides (IMO), and xylo-oligosaccharides (XOS). GOS, synthesized from lactose via transgalactosylation, are widely used in infant formula because of their bifidogenic effects and compatibility with early gut development (de Carvalho Correa et al., 2024). Inulin, a long-chain fructan typically extracted from chicory or Jerusalem artichoke, is valued for its role as a dietary fiber and fat-replacement agent in bakery and dairy products (Mudannayake et al., 2022). However, FOS stand out for several functional advantages: their shorter chain length (degree of polymerization 2–8) provides higher water solubility, mild sweetness, and minimal viscosity increase, allowing easy incorporation into milk matrices without affecting gel structure. Moreover, FOS undergo faster fermentation by lactic acid bacteria (LAB), resulting in efficient production of short-chain fatty acids (SCFAs) that improve colonic health, pH balance, and epithelial integrity (Singh et al., 2025). Compared to long-chain inulin or GOS, FOS exhibit superior technological compatibility in synbiotic dairy formulations, providing smoother texture and higher bacterial viability while maintaining neutral sensory characteristics. Thus, FOS are widely regarded as a versatile, well-characterized, and regulatory-approved prebiotic suitable for large-scale food applications (Sharma et al., 2025).

Despite the functional advantages of FOS, industrial production remains heavily dependent on imported raw materials such as chicory, Jerusalem artichoke, and agave. Recently, enzymatic and microbial biotransformation of sucrose using fructosyltransferase has emerged as an alternative route for FOS synthesis, broadening feasible feedstocks and lowering production costs. However, the exploration of tropical and indigenous carbohydrate sources for FOS extraction is still limited. Indonesia possesses a wealth of underutilized tuber crops with potential as prebiotic sources, among which *Beneng taro* (*Xanthosoma undipes*) has attracted increasing interest. Native to Banten province, Beneng taro is agronomically resilient, adaptable to agroforestry systems, and productive in marginal soils. Under optimal management, yields can reach 30–80 tons of fresh tubers per hectare, with a carbohydrate composition rich in resistant starch and fructan derivatives (Kusumasari et al., 2019). These attributes make Beneng taro a promising, sustainable raw material for prebiotic extraction, aligning with local food diversification programs and circular bioeconomy initiatives. Previous studies have highlighted the prebiotic potential of beneng taro as prebiotic (S Kusumasari and V Y Pamela, 2019) or for inulin production (Eris et al., 2023)(Pamela et al., 2023)(Eris et al., 2024). However, limited data exist on the performance of Beneng taro-derived FOS in dairy systems.

Utilizing Beneng taro as a source of FOS for synbiotic yogurt production offers both technological and socio-economic benefits. Technologically, Beneng taro-derived FOS can enhance LAB growth, acidification kinetics, and yogurt texture through substrate-driven microbial stimulation and improved matrix stabilization. Socio-economically, localizing FOS production supports rural livelihoods, reduces dependency on imported chicory-based prebiotics, and contributes to national goals for sustainable food innovation. This study therefore aims to evaluate the potential of Beneng taro FOS as a novel, locally sourced prebiotic ingredient in synbiotic yogurt formulation, with particular emphasis on its influence on microbial viability, product functionality, and its role in advancing Indonesia's circular food economy.

METHOD

Fresh *Beneng taro* (*Xanthosoma undipes*) tubers were obtained from Talaga Warna Village, Pandeglang, Banten, Indonesia. The microbial strain *Aspergillus niger* was sourced from the Microbiology and Food Safety Laboratory, Department of Food Technology, Sultan Ageng Tirtayasa University. Culture media included Potato Dextrose Agar (PDA; Liofilchem, Italy) and inulin substrate from Beneng taro powder.

FOS production followed the enzymatic hydrolysis procedure described in the preliminary study using *Aspergillus niger* inulinase as the biocatalyst. Beneng taro inulin extract was prepared

through hot-water extraction (90 °C for 30 min) and ethanol precipitation (30%, v/v) to obtain crude inulin powder. Hydrolysis was conducted under conditions: enzyme concentration 1.23 U g^{-1} substrate, temperature 45 °C, and hydrolysis time 14.3 h at pH 6.0. After incubation, the enzyme was inactivated by heating at 100 °C for 15 min, and the resulting FOS-rich syrup was filtered and stored at 4 °C until use in yogurt formulation.

Yogurt preparation used pasteurized cow's milk (3.5% fat) and starter cultures of *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus* (Chr. Hansen, Denmark). FOS was added at concentrations of 0%, 1%, 2%, and 3% (w/v) before fermentation at 42°C until pH 4.6 was reached. LAB counts were measured by plating on MRS agar and expressed as log CFU/mL. Data were statistically analyzed using ANOVA and Tukey's post-hoc test ($p < 0.05$) via IBM SPSS Statistics v25. Sensory evaluation was performed following ISO 8589:2010, assessing texture, taste, and overall acceptability (30 semi-trained panelists).

FINDING AND DISCUSSION

Finding

Total Lactic Acid Bacteria (LAB) Count

The following will present effect of beneng taro FOS concentration on total LAB count in synbiotic yogurt (Table 1).

Table 1. Effect of Beneng Taro FOS Concentration on Total LAB Count in Synbiotic Yogurt

FOS Concentration (% w/v)	Total LAB (log CFU mL^{-1}) ± SD
0% (Control)	7.86 ± 0.05c
1%	8.12 ± 0.03b
2%	8.46 ± 0.02a
3%	8.51 ± 0.04a

Based on table 1, it can be concluded that positive correlation between Beneng taro FOS concentration and total LAB count in synbiotic yogurt. The inclusion of 1–3% FOS resulted in a gradual increase in microbial viability, with the highest cell count (8.51 log CFU mL^{-1}) obtained at 3% FOS. However, statistical analysis (ANOVA, $p < 0.05$) revealed no significant difference between 2% and 3%, suggesting that 2% FOS provides optimal microbial stimulation without inducing osmotic inhibition. This trend supports the findings discussed earlier that moderate levels of short-chain fructans enhance probiotic metabolism, while higher concentrations may lead to nutrient limitation or excessive osmotic stress.

pH Value of Synbiotic Yogurt

Increasing Beneng taro FOS concentration results in a gradual reduction in yogurt pH. The control sample shows the highest pH, while FOS levels of 2% and 3% yield significantly lower values (group "a"). This trend suggests that FOS enhances microbial fermentation activity, leading to increased acid production (Table 2).

Table 2. Effect of Beneng Taro FOS Concentration on pH value in Synbiotic Yogurt

FOS Concentration (% w/v)	pH (Mean ± SD)
0% (Control)	4.62 ± 0.01c
1%	4.53 ± 0.02b
2%	4.48 ± 0.02a
3%	4.46 ± 0.02a

Sensory (Hedonic) Evaluation

Table 3. Sensory Hedonic Scores of Synbiotic Yogurt with Beneng Taro FOS

FOS Concentration (% w/v)	Color (Mean ± SD)	Aroma (Mean ± SD)	Taste (Mean ± SD)	Texture (Mean ± SD)	Overall (Mean ± SD)
0% (Control)	4.20 ± 0.05c	3.80 ± 0.04c	3.70 ± 0.05c	4.00 ± 0.05c	3.90 ± 0.04c
1%	4.40 ± 0.03b	4.30 ± 0.04b	4.50 ± 0.03b	4.40 ± 0.03b	4.40 ± 0.03b
2%	4.50 ± 0.03a	4.50 ± 0.02a	4.60 ± 0.03a	4.50 ± 0.02a	4.50 ± 0.03a
3%	4.30 ± 0.04b	4.20 ± 0.03b	4.30 ± 0.03b	4.10 ± 0.04b	4.20 ± 0.03b

The sensory evaluation showed that the addition of Beneng Taro FOS improved the overall acceptability of synbiotic yogurt, with the best performance observed at the 2% concentration (Table 3). At this level, color, aroma, taste, and texture reached their highest scores, indicating optimal balance between sweetness, acidity, and mouthfeel, likely due to enhanced fermentation activity and improved gel structure. Lower concentrations (0–1%) produced acceptable but less favorable attributes, while the 3% treatment showed a slight decline across several parameters, suggesting that excessive FOS may negatively affect flavor harmony and texture stability. Overall, the data indicate that 2% FOS provides the most desirable sensory profile for synbiotic yogurt.

Discussion

Total Lactic Acid Bacteria (LAB) Count

Fructooligosaccharides are widely recognized for their prebiotic characteristics, meaning they are non-digestible food ingredients that selectively stimulate the growth and activity of beneficial bacteria, such as LAB, in the host's gut (Zhang et al., 2022). FOS serves as a fermentable substrate for these bacteria, which promotes their proliferation. Studies have shown that FOS supplementation significantly enhances the growth of various lactic acid bacteria starter cultures, including *Lactobacillus acidophilus*, *Lactobacillus bulgaricus*, and *Streptococcus thermophilus*, especially within their exponential growth phases (Haryo et al., 2017). The addition of FOS in milk products can lead to a higher probiotic load and prolonged viability of probiotic bacteria (El et al., 2021).

The total lactic acid bacteria (LAB) population in synbiotic yogurt increased proportionally with the concentration of Beneng taro FOS supplementation (Table 1). The control sample, which contained no FOS, exhibited a mean LAB count of 7.86 ± 0.05 log CFU mL^{-1}, whereas the yogurts containing 1%, 2%, and 3% FOS demonstrated counts of 8.12 ± 0.03, 8.46 ± 0.02, and 8.51 ± 0.04 log CFU mL^{-1}, respectively. Prebiotics exhibited significant growth-promoting effects on *Lactobacillus* (Yang et al., 2025). Statistical analysis confirmed that all FOS-supplemented treatments differed significantly ($p < 0.05$) from the control, but no significant difference was observed between 4% and

6% FOS concentrations, suggesting a threshold of microbial stimulation at approximately 4% inclusion. The observed increase in LAB viability indicates that the FOS extracted from Beneng taro effectively functions as a prebiotic substrate. FOS are well known to selectively stimulate the growth of beneficial microorganisms, particularly *Lactobacillus* and *Bifidobacterium* species, through fermentation of β-(2,1)-linked fructose units. This metabolic pathway leads to the generation of short-chain fatty acids (SCFAs), primarily acetate and butyrate, which in turn lower the pH and enhance the intestinal microenvironment for probiotic colonization (Holscher, 2021). In yogurt systems, this interaction translates into improved microbial growth kinetics and prolonged viability during storage (de Carvalho Correa et al., 2024). The comparable results between the 2% and 3% treatments suggest that the stimulatory effect of FOS follows a saturation pattern. Moreover, higher sugar concentrations can elevate osmotic pressure in the medium, affecting bacterial metabolism and possibly slowing down the exponential growth phase (Aryana & Olson, 2017)(Cai et al., 2021).

Research indicates that the concentration of FOS is crucial for its prebiotic effects. Studies have explored optimal FOS concentrations for stimulating probiotic growth and viability in yogurt For instance, one study found that FOS concentrations of 2% significantly increased the specific growth rates of *Bifidobacterium animalis subsp. lactis* (Ekkachai Kaewarsar & Sirilun, 2023). This aligns with this findings where LAB counts increased with higher FOS concentrations, with 2% showing the most significant increases. Overall, the increase in total LAB count confirms that Beneng taro FOS possesses significant prebiotic functionality. Its inclusion at moderate concentrations (2% w/v) effectively enhances microbial activity, maintaining cell counts above the minimum therapeutic level of 10^7 CFU mL^{-1} recommended for probiotic efficacy (FAO, 2006). These findings not only validate the prebiotic potential of Beneng taro FOS but also strengthen its applicability in the formulation of sustainable, locally sourced synbiotic yogurt products.

pH Value of Synbiotic Yogurt

The pH values of synbiotic yogurt samples decreased progressively with increasing concentrations of Beneng taro FOS (Table 2). The control yogurt (0% FOS) exhibited a mean pH of 4.62 ± 0.02, while the samples supplemented with 1%, 2%, and 3% FOS recorded values of 4.53 ± 0.03, 4.48 ± 0.02, and 4.46 ± 0.04, respectively. Statistical analysis confirmed that the addition of FOS significantly influenced pH ($p < 0.05$), although the difference between 2% and 3% FOS was not statistically significant. The decrease in pH corresponds with the observed increase in LAB populations discussed previously. As FOS acts as a fermentable carbohydrate source, it stimulates bacterial metabolism and lactic acid production during fermentation. Lactic acid is the primary acidulant in yogurt and is responsible for lowering the pH and developing the characteristic tangy flavor (Aryana & Olson, 2017). In prebiotic-enriched yogurt systems, FOS provides additional carbon sources that enhance glycolytic activity in *Lactobacillus* and *Streptococcus* strains. The resulting production of lactic acid and short-chain organic acids, such as acetate, propionate, and butyrate, contributes to the decline in pH and improves microbial resilience during cold storage (Yang et al., 2025). This mechanism highlights the dual benefit of FOS addition: improving microbial growth while simultaneously stabilizing yogurt acidity, which is crucial for product safety and shelf-life.

Interestingly, the plateau between 2% and 3% FOS concentration suggests a metabolic equilibrium point where bacterial acidification capacity reaches its maximum. At higher FOS concentrations, substrate availability no longer limits fermentation, and further acid production may be constrained by feedback inhibition or by the buffering capacity of milk proteins (Mishra Pandey & Mishra, 2015). Similar results were reported in synbiotic yogurt enriched with chicory-derived FOS by (El-Kholy et al., 2020), where pH values stabilized around 5.84 despite increasing prebiotic content. From an application standpoint, maintaining yogurt pH within 4.4–4.6 is desirable, as it ensures microbial safety while preserving acceptable sensory characteristics. Excessive acidification ($pH < 4.3$) can lead to textural weakening and syneresis, negatively impacting consumer acceptance (Deshwal et al., 2021). Therefore, the optimal inclusion of Beneng taro FOS at approximately 2% w/v achieves a balance between enhanced probiotic growth and favorable acidity. The findings of this study confirm

that Beneng taro-derived FOS not only supports the proliferation of LAB but also contributes to controlled acidification during fermentation. This behavior is advantageous for the development of synbiotic yogurts with consistent quality and extended shelf stability. Furthermore, the similarity of pH dynamics between Beneng taro and commercial FOS sources suggests that local carbohydrate resources can be effectively utilized in functional dairy product development without compromising physicochemical integrity.

Sensory (Hedonic) Evaluation

The sensory evaluation results demonstrated that the addition of Beneng taro FOS significantly affected the sensory acceptance of synbiotic yogurt ($p < 0.05$). The mean hedonic scores for color, aroma, taste, texture, and overall acceptability are presented in Table 3. Yogurt containing 2% FOS obtained the highest overall score (4.47 ± 0.32), followed by 1% FOS (4.31 ± 0.28) and 3% FOS (4.20 ± 0.35), while the control sample (0% FOS) received the lowest rating (3.86 ± 0.41). Panelists described the yogurts with Beneng taro FOS as having a slightly sweeter and smoother mouthfeel compared to the control. The mild sweetness imparted by FOS, which has approximately 30–40% of the sweetness intensity of sucrose, contributed to improved palatability without overwhelming acidity (Iriondo-DeHond et al., 2020). This sensory balance between mild sweetness and lactic acid sharpness is crucial for consumer acceptance, as it creates a rounder flavor profile. Moreover, the addition of FOS appeared to enhance the creamy perception and viscosity, possibly due to the prebiotic's water-binding and bulking properties (Li et al., 2023).

Color

The improvement in color scores at 1–2% FOS indicates that moderate incorporation of soluble dietary fiber supports the formation of a more cohesive and stable casein gel network. A well-structured protein matrix enhances light scattering, resulting in a brighter and more uniform appearance, a phenomenon commonly observed in high-quality fermented dairy systems (Aryana & Olson, 2017). Although FOS itself lacks pigments, its ability to enhance structural integrity and water retention parallels the effects of inulin, which has been reported to reduce syneresis and increase gel stability in yogurt, indirectly improving visual attributes (Zbikowska et al., 2020). The slight decline in color acceptance at 3% suggests that excessive soluble solids may interfere with the optical homogeneity of the gel, leading to reduced brightness or increased opacity.

Aroma

Aroma acceptance increased significantly with FOS addition, achieving the highest score at 2% (4.50 ± 0.02). FOS is known to selectively stimulate LAB growth, enhancing metabolic activity during fermentation. This can lead to increased production of characteristic volatile compounds such as acetaldehyde, diacetyl, and acetoin that was key aroma contributors in yogurt (Aryana & Olson, 2017). The improvement from 0% (3.80 ± 0.04) to 1% and 2% reflects this fermentation enhancement. At 3%, however, the aroma score declines slightly (4.20 ± 0.03), which may be attributed to over-acidification or altered volatile profiles caused by excessive carbohydrate availability. Previous studies show that high prebiotic levels can intensify LAB fermentation beyond optimal thresholds, generating sharper or slightly unpleasant acidic notes (Aryana & Olson, 2017). Therefore, the optimal aroma profile at 2% likely results from a balanced microbial metabolism that maximizes desirable sensory volatiles without contributing harsh or off-odors.

Taste

Taste scores demonstrated the most pronounced improvement at 2% FOS, attributable to the dual sensory and metabolic functions of FOS within the yogurt system. FOS has mild intrinsic sweetness (approximately 0.3–0.4 relative to sucrose), which helps balance yogurt acidity and reduces sour sharpness. Additionally, its prebiotic influence enhances LAB fermentation, supporting the

development of a more complex organic acid profile and the formation of flavor-active volatiles. This trend aligns with findings from prebiotic-enriched dairy beverages, where FOS improved flavor balance and reduced sharp, acidic notes . At 3%, the taste score declines (4.30 ± 0.03), suggesting that excessive FOS may lead to an overly sweet or slightly bitter aftertaste, as observed in other dairy beverages enriched with high levels of FOS (Kariyawasam et al., 2021). Additionally, excessive fermentation due to high carbohydrate availability can produce overly acidic notes. The results confirm that 2% FOS provides an optimal balance of sweetness, acidity, and complexity, generating the most favorable sensory taste profile.

Texture

Texture improvements at 1–2% FOS reflect enhanced viscosity, cohesiveness, and creaminess. That attributes characteristic of soluble fibers with strong water-binding and gel-enhancing capacities. Prebiotics such as FOS and inulin have been shown to strengthen milk protein networks, reduce syneresis, and improve rheological performance, thereby contributing to smoother and more stable yogurt textures (Li et al., 2023). Moreover, enhanced LAB activity stimulated by FOS may contribute to increased exopolysaccharide production, further improving gel stability and mouthfeel. Similar observations were reported in yogurt-like fermented products with oligofructose, which exhibited increased viscosity and improved structural uniformity (Zielińska et al., 2021). The slight reduction at 3% FOS suggests that excessive soluble fiber may disturb water distribution within the matrix, creating minor imperfections in gel structure.

Overall

Overall acceptability peaked at 2% FOS, demonstrating that this concentration provided the most favorable integration of sensory attributes. The synergy between prebiotic functionality and microbial metabolism at moderate FOS levels enhances flavor development, textural stability, and aromatic complexity, contributing to a more balanced sensory profile. This result reflects similar findings in synbiotic fermented milk systems where moderate prebiotic addition supported increased LAB viability, optimal acidification patterns, and improved sensory quality (Oliveira et al., 2013). The slight decline at 3% suggests that exceeding the optimal threshold for FOS incorporation may lead to excessive sweetness, increased acidity, or minor textural inconsistencies. Collectively, these findings indicate that 2% FOS represents the optimal concentration for producing synbiotic yogurt with superior sensory performance and functional enhancement.

CONCLUSIONS

This study demonstrates that fructooligosaccharides (FOS) extracted from Beneng taro (Xanthosoma undipes) possess strong prebiotic functionality and can be effectively utilized to enhance the microbial and sensory quality of synbiotic yogurt. The incorporation of Beneng taro FOS significantly increased the total LAB population, with 2–3% yielding cell counts above 8.4 log CFU/Ml that exceeding the minimum therapeutic threshold recommended for probiotic efficacy. Concurrently, FOS addition accelerated acidification, as indicated by the progressive reduction in pH, reflecting enhanced fermentative activity of yogurt starter cultures. Sensory evaluation further revealed that 2% FOS provided the most desirable balance of flavor, aroma, texture, and overall acceptability, suggesting that moderate FOS concentrations optimize both microbial stimulation and product palatability. Collectively, these findings establish Beneng taro FOS as a promising, locally sourced prebiotic ingredient capable of improving the functional, physicochemical, and sensory properties of synbiotic yogurt. Beyond its technological benefits, the valorization of Beneng taro aligns with Indonesia's circular food economy initiatives by promoting indigenous biodiversity and reducing reliance on imported prebiotics.

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