International Journal of Sustainable Social Culture, Science Technology, Management, and Law Humanities, 2(1), (2025)

Fortification of Yogurt with *Moringa Leaf Extract* (*Moringa oleifera*) on Quality and Quality as a Functional Food: A Review

Rosidi Azis[1], Juniarti Wulan Lestari[1], Eunike Sri Puspaningsih[1] Muqtafiah[1]

[1]Agriculture Technology, Universitas Kristen Cipta Wacana, Malang, Indonesia

Article history
Received: 30 May 2025
Revised: 10 June 2025
Accepted: 25 June 2025

Keywords
Moringa oleifera, yoghurt, antioxidant activity, fortification, sensory evaluation

Abstract
The incorporation of natural bioactive compounds into dairy products has gained increasing attention due to their potential to enhance nutritional value and functional properties. *Moringa oleifera*, commonly known as the drumstick tree, is a nutrient-dense plant rich in polyphenols, flavonoids, vitamins, and minerals, making it a promising candidate for yoghurt fortification. This review evaluates the impact of *Moringa oleifera* leaf extract on the physicochemical, microbiological, antioxidant, and sensory attributes of yoghurt. Data from recent studies (2014 - 2024) indicate that the addition of *Moringa oleifera* extract at concentrations up to 0.5% significantly improves total phenolic content, antioxidant activity (DPPH and ABTS assays), water holding capacity (WHC), and viscosity, while maintaining acceptable pH levels and supporting probiotic viability. However, higher concentrations may lead to undesirable sensory characteristics such as astringency and greenish coloration, which can affect consumer acceptance. Optimization of extraction methods, fortification levels, and formulation strategies such as encapsulation or blending with other natural ingredients is recommended to balance functionality and sensory appeal. Overall, yoghurt fortified with *Moringa oleifera* extract demonstrates potential as a functional food with enhanced antioxidant properties and improved nutritional profile. Further research is needed to assess long-term stability and in vivo health benefits.

1. Introduction

Yogurt is one of the fermented milk products that is popular worldwide because of its complete nutritional content and probiotic benefits for digestive health and the immune system (Taheur et al., 2023). In addition, yogurt also has the potential as a functional food matrix that can be fortified with bioactive ingredients to increase its nutritional value and biological activity. One of the fortification ingredients that has attracted attention lately is *Moringa oleifera* leaf extract, which is known to be rich in antioxidants, vitamins, minerals, and phenolic and flavonoid compounds (Anwar et al., 2007; Ahale, 2022, Sonu, 2023). *Moringa leaves* have long been used in traditional medicine for their various health benefits, including anti-inflammatory, antidiabetic, and antioxidant effects (Infante-Menéndez et al., 2020; Meireles et al., 2020; Chris et al., 2023). Phenolic compounds such as quercetin, kaempferol, chlorogenic acid, and rutin in *moringa leaves* extract are known to have a high capacity to ward off free radicals, thus potentially increasing antioxidant activity in food products such as yogurt (Karthivashan et al., 2020). In addition, *moringa* leaf extract also contains vegetable proteins that can interact with milk proteins, affecting the texture and physical stability of yogurt during storage (Amini & Ghoranneviss, 2016; Adepoju et al., 2024).

Several studies have shown that the addition of *moringa* leaf extract to yoghurt formulation can improve the physicochemical quality, antioxidant activity, and viability of probiotic bacteria without significantly affecting sensory properties (Lisak Jakopović et al., 2022; Sari et al., 2025). However, there are several challenges in its application, such as astringent taste due to high phenolic compounds, green discoloration that is less acceptable to most consumers, and interactions with milk components that can affect gel stability (Adepoju & Selezneva, 2024). The purpose of this study is to provide a comprehensive overview of the effect of *moringa* leaf extract fortification on yoghurt quality, including organoleptic characteristics, viscosity, pH, and antioxidant activity, both in vitro and in vivo. This review also discusses

*Corresponding author, email: rosidiazis1953@gmail.com
doi: https://doi.org/10.71131

the types of extraction solvents, optimal concentrations, and the most appropriate fortification methods to produce functional yoghurt products with high market acceptance.

2. Method

The review method was carried out systematically by referring to the narrative review approach to evaluate the effect of moringa leaf extract fortification (*Moringa oleifera*) on the physicochemical quality, antioxidant activity, and sensory characteristics of yoghurt. The process began with a literature search using Google Scholar, ScienceDirect, PubMed, and Scopus databases with keywords such as "yogurt + *moringa oleifera*", "fortified yogurt + antioxidant activity", and "bioactive compounds in dairy products". Inclusion criteria included experimental studies from 2014–2024 involving yoghurt formulation with *moringa* leaf extract and presenting data on pH, viscosity, total phenolics, antioxidant activity (DPPH, ABTS), probiotic viability, and sensory evaluation. References that were not relevant or did not meet the criteria were excluded to maintain focus and validity. The data that was successfully collected was then synthesized in tabular form and discussed critically based on product quality parameters. In addition, aspects of methodology, interpretation of results, and sensory acceptance were also evaluated to provide a comprehensive picture. This review is complemented by the latest scientific references to support the validity of claims and product development recommendations. The stages of this study can be explained completely in Figure 1.

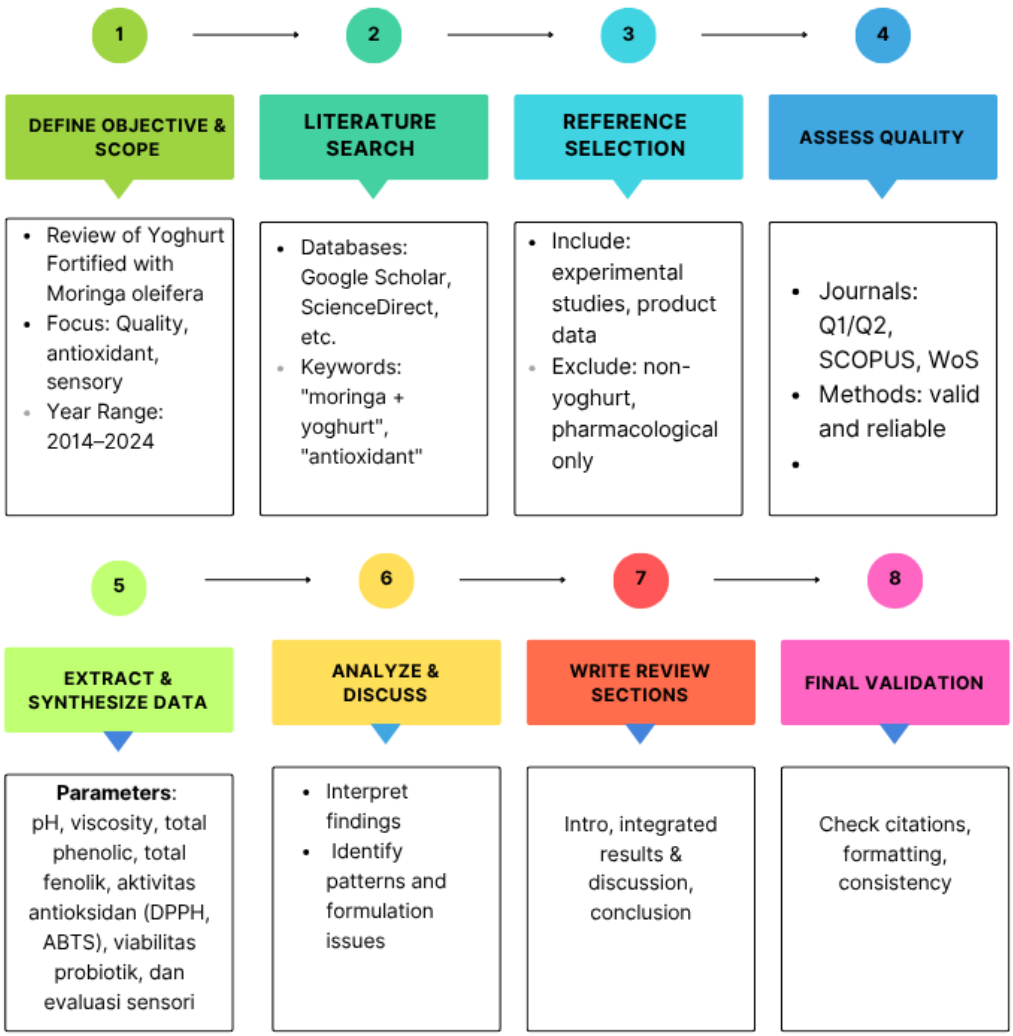

Figure 1. Data exploration stages in research

3. Result and Discussion

3.1. Fortification of *Moringa oleifera* Extract on Yogurt

Fortification of yogurt with *Moringa oleifera* leaf extract has been shown to improve various parameters of physicochemical, microbiological, antioxidant activity, and overall nutritional value. Based on the data from the previous Table 1, increasing the concentration of *Moringa oleifera* extract from 0.1% to 0.5% showed a significant effect on the characteristics of yogurt, although there are several sensory aspects that need to be considered to remain in accordance with consumer preferences.

Parameter	Control (No *Moringa*)	0.1% *Moringa Oleifera*	0.3% *Moringa Oleifera*	0.5% *Moringa Oleifera*	Reference
pH	4.52 ± 0.03	4.50 ± 0.02	4.47 ± 0.01	4.45 ± 0.02	Lisak Jakopović et al., 2022
Acidity level (AL)	0.85% ± 0.02	0.86% ± 0.01	0.89% ± 0.03	0.91% ± 0.02	Adepoju & Selezneva, 2024 Adepoju et al., 2024
Water Holding Capacity (WHC) (%)	78.4 ± 0.5	79.8 ± 0.6	81.3 ± 0.4	82.5 ± 0.3	Sari et al., 2025
Viscosity (Pa·s)	0.302 ± 0.005	0.315 ± 0.004	0.340 ± 0.006	0.351 ± 0.007	Lisak Jakopović et al., 2022
Total Solids (%)	12.4 ± 0.2	12.7 ± 0.1	13.1 ± 0.2	13.5 ± 0.3	Amini & Ghoranneviss, 2016
Protein Content (g/100g)	3.5 ± 0.1	3.6 ± 0.1	3.8 ± 0.1	4.0 ± 0.1	Sari et al., 2025
Mineral Content (mg/100g): - Potassium - Calsium - Fe	160 120 0.3	175 135 0.5	190 145 0.7	210 160 1.0	Anwar et al., 2007 Lisak Jakopović et al., 2022
Total Phenolic (mg GAE/100g)	5.10 ± 0.20	10.10 ± 0.30	14.20 ± 0.40	16.30 ± 0.50	Zhang et al., 2019
Antioxidant activity (%) - DPPH - ABTS	40.0% 42.5%	65.0% 68.0%	72.0% 75.0%	78.0% 81.0%	Hsu et al., 2013 Sonu, 2023
Viability of Probiotic Bacteria (log CFU/g): - *Lactobacillus acidophilus* - *Streptococcus thermophilus*	7.2 ± 0.1 7.0 ± 0.1	7.3 ± 0.1 7.1 ± 0.1	7.4 ± 0.1 7.2 ± 0.1	7.5 ± 0.1 7.3 ± 0.1	Amini & Ghoranneviss, 2016 Parrón et al., 2018
Sensory evaluastion (Hedonic Scale 1–9): - Taste - Texture - Flavour - Colour - General Preferences	7.5 7.6 7.4 7.8 7.6	7.8 7.9 7.7 7.6 7.8	7.6 7.8 7.5 7.3 7.6	7.2 7.5 7.1 6.8 7.2	Diantoro et al., 2015 Vijay et al., 2022

3.2. Effect on pH and Acidity Level

The addition of *Moringa oleifera* extract caused a slight decrease in the pH of yoghurt from 4.52 (control) to 4.45 in the 0.5% formulation (Table 1). At the same time, the acidity level (AL) increased from

0.85% to 0.91%, indicating that *moringa* leaf extract can affect the activity of lactic acid bacteria during fermentation (Lisak Jakopović et al., 2022). This decrease in pH is also thought to originate from phenolic compounds in the extract which have selective antimicrobial effects, accelerating the production of lactic acid without interfering with the viability of probiotics (Sari et al., 2025). The addition of *moringa* leaf extract (*Moringa oleifera*) to yoghurt formulation has a direct effect on changes in pH and AL. The data showed that increasing the extract concentration up to 0.5% caused a slight decrease in pH from 4.52 (control) to 4.45, while AL increased from 0.85% to 0.91%. These changes indicate an interaction between the active compounds in the extract and the fermentation process that occurs during yoghurt production.

Moringa oleifera extract contains a number of phenolic compounds such as quercetin, kaempferol, chlorogenic acid, and rutin which have dual biological activities: as strong antioxidants and selective antimicrobial agents (Infante-Menéndez., 2020; Sonu, 2023). In the context of yoghurt, these compounds not only enrich the nutritional profile of the product, but can also modulate the activity of lactic acid bacteria (LAB), especially Streptococcus thermophilus and Lactobacillus bulgaricus, which are responsible for the decrease in pH during fermentation. Research by Zhang et al. (2019) showed that phenolic compounds from plants can increase LAB metabolism through a mild prebiotic effect, thereby accelerating lactic acid production and accelerating pH reduction. This is in line with the results in the table, where yogurt fortified with *moringa* leaf extract achieved a lower pH and higher AC compared to the control. However, several studies have also noted that too high an extract concentration (>0.5%) can inhibit the growth of certain microbes due to the antimicrobial effects of phenolic compounds (Zhang et al., 2019; Shivanna & Rao, 2024). Therefore, it is important to find the optimal point of fortification so as not to interfere with the fermentation process and viability of probiotics.

Changes in pH and AL not only affect the taste and texture of yogurt, but also the microbiological stability and shelf life of the product. A moderate decrease in pH helps create an environment that is less supportive of the growth of pathogenic or spoilage microbes, thereby increasing the durability of yogurt during storage (Gomes et al., 2023). In addition, increasing AL can increase the stability of milk protein gels, prevent syneresis, and provide a fresher and more sour taste that consumers prefer. However, too large an increase in AL (>0.95%) can cause a taste that is too sour and uncomfortable for some consumers, especially those who are sensitive to acid (Diantoro et al., 2015; Lisak Jakopović et al., 2022).

3.3. Water Holding Capacity and Viscosity

The addition of *Moringa oleifera* leaf extract to yoghurt formulation had a significant positive effect on two important parameters in texture quality, namely Water Holding Capacity (WHC) and viscosity. The data showed that WHC increased from 78.4% (control) to 82.5% at 0.5% fortification, while viscosity increased from 0.302 Pa s to 0.351 Pa s. These changes indicate an increase in the stability of the gel structure and the overall texture quality of yoghurt.

Yogurt fortified with Mor*inga oleifera* leaf extract showed an increase in WHC from 78.4% (control) to 82.5% at a concentration of 0.5%, indicating the product's ability to maintain a more stable gel structure and reduce syneresis (Adepoju & Selezneva, 2024). In addition, the viscosity of yoghurt also increased gradually from 0.302 Pa s (control) to 0.351 Pa s at 0.5% fortification. This increase is thought to be due to the interaction between milk protein and polyphenolic compounds from *Moringa* leaves which form a denser protein network (Amini & Ghoranneviss, 2016; Gomes et al., 2023). *Moringa oleifera* extract contains phenolic compounds such as quercetin, kaempferol, and chlorogenic acid, which are known to have high affinity for milk proteins, especially casein (Zhang et al., 2019). The interaction between phenolics and proteins helps form a denser gel network during the fermentation process, thereby increasing the ability of yoghurt to retain water (WHC) and providing a thicker texture (increased viscosity). This effect was also reported by Amini & Ghoranneviss. (2016), where fortification of *Moringa* leaf powder up to 0.5% not only increased WHC but also reduced syneresis by 21%, making the product more stable during storage. This stability is very important because excessive syneresis can cause whey separation, which has a negative impact on appearance and consumer acceptance. Viscosity is an important parameter that determines the mouthfeel or texture impression when consumed. Increasing viscosity from 0.302 Pa.s (control) to 0.351 Pa.s at 0.5% fortification showed improvements in the mouthfeel and thickness of yoghurt. This is supported by the study of Lisak Jakopović et al. (2022), which noted that increasing viscosity improved sensory scores for texture and mouthfeel on a test panel. However, increasing viscosity too much (>0.36 Pa.s) can potentially reduce consumer acceptance if it is

perceived as too thick or sticky. Therefore, it is important to balance the increase in viscosity with other sensory factors such as taste and color to maintain acceptance by the wider market.

3.4. Total Solids and Protein Content

Fortification of yoghurt with *Moringa oleifera* leaf extract not only increased antioxidant activity and texture stability, but also provided significant nutritional benefits. Data showed that the addition of extract up to 0.5% increased total solids from 12.4% to 13.5%, while protein content increased from 3.5 g/100g to 4.0 g/100g. This increase indicates that *Moringa* leaf extract can function as a highly nutritious fortification material. The total solids content increased from 12.4% to 13.5%, while protein content increased from 3.5 g/100g to 4.0 g/100g due to the addition of *Moringa* leaf powder or extract. This shows that fortification not only provides functional benefits but also increases the nutritional value of yoghurt, making it a highly nutritious food alternative, especially in areas with protein deficiency (Anwar et al., 2007).

Moringa leaves are known to have a high and balanced protein content, covering all essential amino acids in good proportions (Anwar et al., 2007). This vegetable protein, although not completely soluble in water, can be well dispersed in the milk matrix during the homogenization and fermentation process. The interaction between vegetable protein from *Moringa* leaves and milk proteins such as casein helps strengthen the yoghurt gel structure, increasing total solids and the physical stability of the final product (Amini & Ghoranneviss, 2016; Shivanna & Rao, 2024; Adepoju et al., 2024). Research by Adepoju & Selezneva (2024) showed that moringa leaf powder added to yoghurt formulation not only increased protein content but also improved the consistency and gel stability index values. This confirms that *moringa* leaf extract is not only a source of bioactive compounds, but also an additional important nutrient for functional products. Increasing total solids is very important in the development of quality yoghurt because it can improve a thicker and softer texture, reduce syneresis or whey separation, and increase the overall nutritional value of the product. Meanwhile, increasing protein levels has a positive impact on taste, satiety, and physiological benefits, especially for consumers who require high protein intake such as athletes, pregnant/lactating mothers, or individuals with nutritional deficiencies (Diantoro et al., 2013; Shivanna & Rao, 2024). In addition, protein also contributes to increasing the viability of probiotic bacteria during fermentation and storage (Zhang et al., 2019).

3.5. Phenolic Content, Minerals and Antioxidant Activity

The addition of *Moringa oleifera* leaf extract to yoghurt formulation significantly increased total phenolics, minerals and antioxidant activity, making it a functional food product with added value. Data showed that total phenolics increased from 5.10 mg GAE/100g (control) to 16.30 mg GAE/100g at 0.5% fortification. Antioxidant capacity in the form of DPPH and ABTS tests also increased dose-dependently, reaching 78% and 81%, respectively at the highest concentration. Fortification of yoghurt with *Moringa oleifera* leaf extract contributed significantly to increasing mineral content, making it a high-nutritional food product. Data showed that the addition of extract up to 0.5% increased the levels of several important minerals such as Potassium (210 mg/100g), Calcium (160 mg/100g) and Iron/Fe (1.0 mg/100g).

Total phenolics also increased from 5.10 mg GAE/100g (control) to 16.30 mg GAE/100g at 0.5% fortification. The antioxidant capacity in the form of DPPH and ABTS tests also increased dose-dependently, reaching 78% and 81% respectively at the highest concentration. These results are in line with the research of Sonu (2023), which reported that *moringa* leaf extract has a competitive antioxidant capacity even compared to synthetic antioxidants. *Moringa* leaves are known as one of the natural ingredients that are very rich in essential minerals (Sari et al., 2025; Lisak Jakopović et al., 2022). According to Anwar et al. (2007) and Hsu et al. (2013), *moringa* leaves contain various important minerals in balanced proportions, including potassium, calcium, magnesium, phosphorus, iron, and zinc. Potassium plays an important role in heart health and nerve function, calcium supports healthy bones and teeth, while iron is a major component of hemoglobin in the blood which is important for oxygen transport .

Research shows that the use of 40% ethanol-water solvent is very effective in extracting active phenolic compounds which significantly improve the functional properties of yoghurt (Tang et al., 2024; Gautier et al., 2022). These phenolic compounds not only act as powerful antioxidants but also help in improving the texture and stability of yoghurt during cold storage (Gautier et al., 2022). In addition, this

extraction method has the advantage of producing a more stable extract compared to pure water or concentrated ethanol-based methods. This stability is important to maintain the quality of the final product and ensure that the health benefits of the bioactive compounds remain optimal throughout the shelf life.

3.6. Viability of Probiotic Bacteria

Fortification of *moringa* leaf extract up to 0.5% did not affect the viability of probiotic bacteria such as Lactobacillus acidophilus and Streptococcus thermophilus. The number of bacteria remained above the minimum probiotic threshold (>10^6 CFU/g) throughout the shelf life, indicating that *moringa* leaf extract can function as a natural prebiotic that supports the growth of good microbes (Amini & Ghoranneviss, 2016). However, some researchers noted that extract concentrations >0.5% can inhibit the growth of certain microbes due to the antimicrobial effects of phenolic compounds (Zhang et al., 2019; Dhawi et al., 2020; Ponka et al., 2022).

Microbiological stability is one of the key aspects in determining the quality of fermented products such as yoghurt. This product contains lactic acid bacteria (LAB), which not only play a role in the fermentation process but also provide probiotic benefits to consumers. However, to ensure that the LAB count remains above the minimum probiotic threshold of 10^6 CFU/g during storage, the product formulation needs to be optimized (Adepoju et al., 2020; Ponka et al., 2022). Fortification of bioactive compounds such as *Moringa oleifera* leaf extract has been shown to maintain microbiological stability while increasing the nutritional value of yoghurt. Research by Primaningrum Dian Indah Sari et al. (2025) showed that the addition of 30% *Moringa oleifera* Lamk. Leaves Extract (MOLE) to frozen yoghurt resulted in a probiotic viability of 8.58±0.52 log CFU/mL, which is high enough to meet probiotic standards (Sari et al., 2025; Elshiekh et al., 2023; Bikhee et al., 2021).

These results are supported by Zhang et al. (2019), who reported that the addition of *moringa* leaf extract supports the growth of probiotics Lactobacillus rhamnosus GR-1 and Streptococcus thermophilus without inhibiting fermentation ability Adepoju et al., 2024). The positive effect of *moringa* leaf extract on LAB viability comes from its nutritional content which is rich in protein, fat, and phenolic compounds. The main phenolic compounds such as kaempferol and quercetin contribute significantly to the antioxidant activity and microbiological stability of yogurt (Sari et al., 2025; Saeed, 2020). In addition, *moringa* leaf extract also has antibacterial effects that can increase the shelf life of yogurt by preventing pathogen contamination. Research by Dhawi et al. (2020) showed that ethanol extract of *moringa* leaves at a concentration of 2% was able to inhibit the growth of Escherichia coli during storage (Adepoju et al., 2024). This effect is due to the ability of the extract to lower the pH of yogurt and create an unfavorable environment for pathogenic microorganisms (Gomes et al., 2023; Obasi et al., 2019; Saeed, 2020). The viability of LAB that persists above the minimum probiotic threshold during cold storage has been verified in several studies. Adepoju & Selezneva (2020) reported that total LAB in yoghurt fortified with *moringa* leaf powder (MOLP) remained above 10^6 CFU/g at all concentrations, with 0.5% MOLP concentration showing the highest growth compared to the control (Adepoju et al., 2024; Obasi et al., 2019). These data indicate that MOLE or MOLP fortification not only improves microbiological stability but also extends the shelf life of the product. The increase in LAB viability is also supported by the study of Hassan et al. (2016), who found that the addition of *moringa* leaf powder up to 0.5% to yoghurt from buffalo milk increased total solids, protein, and amino acids such as alanine, leucine, tyrosine, and glutamate, which function as additional substrates for the growth of probiotic bacteria (Sari et al., 2025; Oyeyinka & Oyeyinka, 2018). However, additions of more than 0.5% can cause undesirable astringent flavors, making it important to optimize fortification levels to balance nutritional benefits with consumer sensory acceptability.

3.7. Sensory Evaluation

Although the physical and chemical quality of yoghurt showed an increase, sensory evaluation showed a decreasing trend in the hedonic score at fortification concentrations of more than 0.3%. The astringent taste derived from phenolic compounds and the dominant green color due to chlorophyll were the main factors influencing consumer acceptance. The taste score decreased from 7.8 (0.1%) to 7.2 (0.5%), and the color score decreased from 7.6 to 6.8. Although the aroma remained stable, changes in color and taste were the main challenges in the formulation of commercial products (Diantoro et al., 2013; Bikheet et al., 2021; Obasi et al., 2019).

Sensory evaluation is an important aspect in the development of food products, because it determines consumer acceptance widely. Data shows that the addition of *Moringa oleifera* leaf extract up to 0.5% has varying impacts on the hedonic score of yoghurt based on the parameters of taste, texture, aroma, color, and general preference. In general, the low concentration formulation (0.1–0.3%) received a positive response from the panelists, with the taste score increasing from 7.5 (control) to 7.8, and the texture and aroma scores remaining stable. However, at a concentration of 0.5%, the sensory score tended to decrease, especially in the taste parameters (7.2) and color (6.8), due to the presence of an astringent taste and a dominant green color that was less acceptable to most panelists (Diantoro et al., 2013; Chis et al., 2022; Tang 2024). The astringent taste that appears in the high formulation is caused by phenolic compounds such as tannins and flavonoids that have a high affinity for salivary proteins, causing a dry and rough sensation in the mouth. This has been reported in several studies on yoghurt fortification with natural ingredients rich in phenolics (Zhang et al., 2019; Hsu et al., 2013). In addition, the presence of chlorophyll in the *Moringa* leaf extract provides a green color that, although visually attractive, often does not match consumer expectations for the usual yellowish-white yoghurt color. However, some panelists noted that the green color gave a "natural" and "healthy" impression, which could be an added value if marketed with the right educational approach.

Sensory evaluation also revealed that the texture and mouthfeel of the yoghurt remained good up to a concentration of 0.3%, even slightly improving due to the increase in viscosity and WHC (El-Gammal et al., 2017; Tang et al., 2024). The aroma of the yoghurt remained neutral without any strong herbal odor interference, indicating that the *moringa* leaf extract did not significantly interfere with the yoghurt's fermentative characteristics. However, at higher concentrations (>0.3%), the aroma was slightly affected and was perceived as "herbal" or "green tea", which were less familiar to most panelists. Therefore, to maximize sensory acceptance, it is important to optimize the formulation, including the use of extraction methods that select low-astringency active compounds, blanching the *moringa* leaves before extraction, or encapsulating the extract to minimize direct contact with the tongue during consumption. A combination approach with other natural ingredients such as honey, fruit extracts, or cocoa powder can also help offset the astringent taste and improve the color of the final product to make it more acceptable to the wider market.

4. Conclusion

Fortification of yoghurt with *Moringa oleifera* leaf extract has been shown to provide significant increases in antioxidant activity, total phenolics, texture stability (viscosity and WHC), and nutrient content such as protein and minerals. The addition of extract up to a concentration of 0.5% did not interfere with the viability of probiotic bacteria and maintained the pH and acidity levels within the range suitable for consumption. However, at higher concentrations (>0.3%), the astringent taste and dominant green color tended to decrease the sensory scores of the test panel, indicating the need for formulation optimization to balance functional benefits and consumer acceptance. With the right fortification approach, yoghurt based on *Moringa* leaf extract has the potential to be developed as a functional food product with high nutritional value that supports public health.

Author Contributions

All authors have equal contributionsto the paper. All the authors have read and approved the final manuscript.

Funding

No funding support was received.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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