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REVIEW ARTICLE

Natural nutraceuticals for enhancing yogurt properties: a review

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Abstract

Yogurt is a major fermented milk product providing probiotics, lactic acid bacteria, vitamins, calcium, and proteins, yet health-beneficial phenolics, flavonoids, anthocyanins, and iron are absent in plain yogurt. These compounds could provide antidiabetic, antiobesity, antimicrobial, and anticancer properties. Here, we review the effect of adding natural functional ingredients in dairy and non-dairy yogurts, with focus on the properties and biological activity of functional yogurts. Properties include color, pH, acidity, water-holding capacity, syneresis, viscosity, structure, fats, microbiology, and flavor. Biological activities comprise antioxidant, antidiabetic, antiobesity, anti-inflammatory, cardioprotective, antibacterial, and anticancer. We found that yogurt from plant-based milk, such as common bean and soy milk, and the addition of functional ingredients, enhanced biological activities of yogurts and improved properties. Functional ingredients provide polysaccharides, phenolics, flavonoids, anthocyanins, and amino acids. Functional ingredients are both natural stabilizers and texturizing materials. The incorporation of functional ingredients improved the contents of phenolics and flavonoids by 96.52 and 97.72%, respectively, increased water-holding capacity by 20–25%, and improved the number of viable cells of lactic acid bacteria. Incorporation reduced syneresis by 15–32% and decreased the loss of fat globules. Moreover, apparent viscosity, texture, microstructure, and sensory properties were enhanced. Biological activities strongly increased, especially antioxidants, which increased from 4.88 to 15.03 mg trolox equivalent per 100 g of yogurt.

Keywords Chemical functional properties · Yogurt · Natural functional ingredients · Nutritional compositions · Biological properties · Non-dairy milk

Introduction

Consumers are now more informed about food and ingredients, especially functional foods, which have drawn much interest for their advantages in preventing several health problems, boosting several physiochemical functions, and providing high nutritional value. Therefore, several recent studies showed increased demand for these beneficial natural products (Crini et al. 2020; Huang et al. 2022; Qasim et al. 2021; Rashwan et al. 2022; Rashwan et al. 2021; Shori 2022; Suwannasang et al. 2022; Tang et al. 2022). Yogurt with functional ingredients is a type of functional food product that has been widely recognized and accepted by consumers; where health-conscious consumers have long considered yogurt to be a health-promoting product that could aid in digestion (Acevedo-Fani et al. 2021; Liu et al. 2022; Mada et al. 2022). Various yogurt formulations are currently being produced to improve the nutritional value, quality properties, and health properties of products, as well as to meet the growing consumer demand for such yogurt (Ban et al. 2022; Rashwan et al. 2022; Shalabi 2022; Wijesekara et al. 2022). Yogurt is one of the most widely consumed fermented milk products made by combining pasteurized milk with lactic acid bacteria, specifically *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* under controlled

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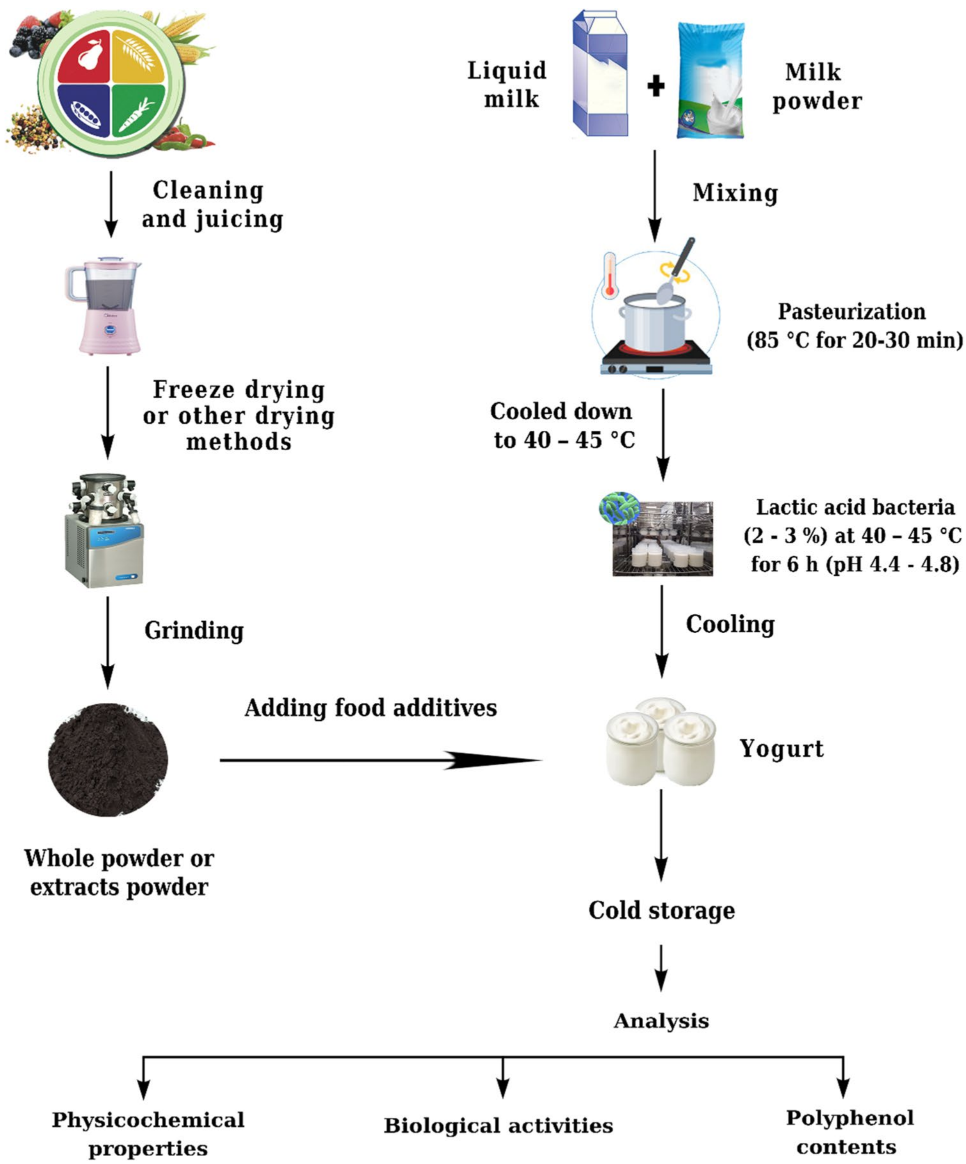

Fig. 1 General method of yogurt production and addition of natural functional ingredients. Typical yogurt can be made from liquid milk and 1–2% milk powder. Natural functional ingredients can be added to yogurt in the form of fresh materials, such as fruit, vegetables, and others, dried forms, or powdered extracts. Natural functional ingredients can be added to yogurt prior to, during, or subsequent to pasteurization and fermentation. Lactic acid bacteria are utilized in the yogurt fermentation process

conditions (Fig. 1) (Deshwal et al. 2021; Rashwan et al. 2022; Wijesekara et al. 2022).

Yogurt consumption can boost the immune system, aid in weight management, and lower the risk of developing cancer, in addition to improving mineral and vitamin absorption due to yogurt's high protein constituents, probiotics, lactic acid bacteria, vitamins, and calcium content, as well as its relatively low-fat content (Gilbert and Turgeon 2021; Wijesekara et al. 2022). However, plain yogurt lacks a variety of nutrients such as phenolics, flavonoids, anthocyanins, iron, and others (Rashwan et al. 2022; Wang et al. 2020); thus, the production of yogurts from non-dairy milk (plant-based milk) and the incorporation of natural functional ingredients such as fruit, vegetable, cereals, and other cannot only improve the chemical composition and health benefits of the yogurt, but can also act as a natural stabilizer and texturizing agent, as well as improve the microstructure, color, and texture of the yogurt (Buchilina 2021; Mohamed Ahmed et al. 2021; Mohammadi-Gouraji et al. 2019). In numerous articles, the influence of adding natural functional ingredients from diverse sources such as fruits, vegetables, leaves, cereals, pomaces, flowers, and others on the physicochemical and functional properties of yogurt, as well as its quality characteristics, microbiological properties, and biological activity, was investigated. Most of these studies demonstrated that adding natural edible ingredients to yogurt improved its chemical composition, biological activity, and quality characteristics (Anuyahong et al. 2020; Chen et al. 2019a; Demirkol and Tarakci 2018; Dong et al. 2022; Du et al. 2022; El-Naggar et al. 2020; Fawzi et al. 2022; Kowaleski et al. 2020; Qiu et al. 2021; Rashwan et al.

2022; Ribeiro et al. 2021; Shariati et al. 2020; Tang et al. 2022; Wang et al. 2020).

Therefore, this review aims to describe the most significant changes critically and comprehensively in the nutritional compositions and quality attributes of dairy and non-dairy milk yogurts after adding natural functional ingredients. Furthermore, this article describes the biological activity of dairy and non-dairy yogurts containing natural edible ingredients. As a result, this review can potentially be a valuable contribution to the field of functional yogurts and pique the interest of both food scientists and industry professionals.

Non-dairy milk yogurt

Lately, the plant-based diet, which involves cereal, legumes, seeds, nuts, fruits, and vegetables, is become one of the most favorable diets with many consumers due to the presence of high nutritional value of the plants, a desire for a healthy lifestyle, environmental awareness, and an aversion to animal cruelty (Aydar et al. 2020; Sridhar et al. 2021a). Therefore, non-dairy milk products such as soybean, mung bean, almond, coconut, pea, and quinoa milk have attracted great attention from both consumers and food scientists due to the presence of some emergencies related to the consumption of dairy milk products with many people such as lactose intolerance, high cholesterol, milk allergies, anemia, and coronary health diseases (Hati et al. 2020; Huang et al. 2022; Kundu et al. 2018; Pachekrepapol et al. 2021; Yang et al. 2021). Non-dairy milk products are available in many countries, especially China, the United States of America, and European countries due to the high production of non-dairy milk substitutes materials such as soybean, mung bean, almond, coconut, pea, and quinoa (Devnani et al. 2022; Rahmatuzzaman Rana et al. 2021). Non-dairy milk products have high nutritional value because they are produced from nutritious materials, including soybean milk, mung bean milk, almond milk, and others, that have a high number of bioactive components including phenolics, flavonoids, procyanidins, and others, as well as non-allergic proteins, dietary fiber, essential fatty acids, minerals, and vitamins (Kowaleski et al. 2020; Lorusso et al. 2018; Ogundipe et al. 2021).

Furthermore, non-dairy milk yogurt is considered one of the better non-dairy milk products because it can reduce cardiovascular risk and diseases of gastrointestinal with improved physiological functions and decrease low bone mass risk, as well as it can show high levels of antioxidants with free radical scavenging properties (Anuyahong et al. 2020; Huang et al. 2022; Lee et al. 2020; Obaroakpo et al. 2020; Sengupta et al. 2016; Sengupta et al. 2019; Shori et al. 2022). However, non-dairy milk yogurt has various negative health effects, including a lack of protein content, low bioavailability of minerals and vitamins, and oral health problems (Aydar et al. 2020). The low bioavailability of vitamins and minerals is due to the presence of some antinutritional factors such as phytic acid, tannins, and trypsin inhibitors (Rashwan et al. 2021; Sorour et al. 2017). Some treatments can overcome these problems, including soaking, cooking, germination, and fermentation (Rashwan et al. 2021; Sorour et al. 2017).

Ma et al. (2021) used a variety of methods to produce neutral pea milk for non-dairy milk yogurt preparation, including alkali water soaking at 25 °C (a), dry dehulling and alkali water soaking (b), boiling water blanching (c), wet dehulling and alkali water soaking (d), as well as boiling water blanching-dehulling and acid water soaking (e), and direct soaking and blending (f) (control). Through volatile components analysis and sensory evaluations, they discovered that pea yogurts prepared from (b), (a), and (d) showed significant improvements in gel hardness, while pea yogurt prepared from (e) provided better flavor than others (Ma et al. 2021). Another challenge faced by yogurt production from non-dairy milk is the unpleasant taste and flavor of produced yogurt. Thus, supplementing non-dairy milk yogurt with some natural functional ingredients such as honeybee, brown rice, berries, apple, grape, pomegranate, nuts, carrots, and beetroot can overcome the alleged unpleasant or poor taste of this kind of yogurt (Huang et al. 2022; Kundu et al. 2018; Ma et al. 2021; Wang et al. 2020; Zannini et al. 2018). For instance, adding milled quinoa to milled soybean at ratios 8:2 and 2:8 presented the best formulations of yogurt and improved the sensory and function evaluation compared to yogurt control (Huang et al. 2022). Besides, adding tapioca starch from 1.0% (weight/weight) improves the sensory property of yogurt-like products from coconut milk, especially the texture attribute (Pachekrepapol et al. 2021).

To summarize, yogurt can successfully be prepared from non-dairy milk such as soybean, mung bean, almond, coconut, pea, and quinoa milk, as well as can overcome the non-dairy milk yogurt limitations by soaking, boiling, or/and blanching the non-dairy milk substitute materials using water or alkali water. Besides, the quality attributes of non-dairy milk yogurt via adding natural functional ingredients.

Natural functional ingredients

Namely, foods or their ingredients can be considered functional foods or ingredients when they beneficially affect sufficiently proven one or more target functions in the body beyond their basic nutritional function in a way that is relevant to either reduction of the risk of disease and/or improving the health state and well-being (Ahmad Ruslan et al. 2021; O'Sullivan et al. 2016; Shahidi 2009; Sridhar et al. 2021b). In recent years, natural functional ingredients have attracted the great attention of many food scientists to produce functional foods that can improve health and wellness circles (Rashwan et al. 2020; Rashwan et al. 2021). Many foods and their ingredients were characterized as functional due to their unique nutritional compositions, such as sorghum, brown rice, beluga black lentils, black beans, berries, apple, grape, jujube, pomegranate, nuts, carrot, beetroot, cauliflower, purple potato, turmeric, cinnamon, salmon, sardines, and others (D'Amelia et al. 2022; Espitia-Hernández et al. 2022; Fadhlizil Fasihi Mohd Aluwi et al. 2022; Feng et al. 2022; Rashwan et al. 2020; Rashwan et al. 2022; Rashwan et al. 2021). For example, sorghum extract contained a large number of bioactive compounds such as anthocyanins 2.4 µg/g, flavonoids 13.6 mg/g, and soluble polyphenols 102.1 mg/g (Bradwell et al. 2018). These compounds are responsible for the biological activity of these foods, where the studies showed that red sorghum contained higher antioxidant activity IC_{50} value of 2,2-diphenyl-1-picrylhydrazyl radicals was 65% compared to white sorghum IC_{50} value of 2,2-diphenyl-1-picrylhydrazyl radical was 22.147% due to the presence of the high amount of total phenolic, tannin, and phytic acid contents in red sorghum (Rashwan et al. 2021; Sorour et al. 2017). Additionally, the fresh jujube contained (three Chinese jujube cultivars) about 1.98–3.12% of titratable acids, 20.35–87.5 µg/g of cAMP, and 41.21–62.72 mg/g of total flavonoids (Chen et al. 2019b).

Furthermore, some natural materials such as strawberry and vanilla can provide flavor compounds, where strawberry flavor contains propylene glycol 74–84%, ethyl alcohol 7–17%, and natural flavoring 6–12%. Moreover, vanilla contains many flavor compounds such as propylene glycols 63–68%, ethyl alcohol 23–28%, natural flavoring 11–16%, water 2–5%, and caramel IV < 0.5% (Oliveira et al. 2021). Besides, *Melastoma dodecandrum* Lour. fruit extracts have shown potent α-glucosidase inhibitory activity due to the presence of a considerable amount of casuarictin that can work well to inhibit α-glucosidase (Xu et al. 2023). Therefore, these foods or their ingredients can be incorporated with several food products to enhance their nutritional value, quality attributes such as texture, color, flavor, taste, shelf-life, and other, and health properties such as antioxidant, antidiabetic, antiobesity, antimicrobial, anticancer, and other (Buchilina 2021; Chen et al. 2019a; Huang et al. 2022; Rashwan et al. 2020; Rashwan et al. 2022; Rashwan et al. 2021; Shahein et al. 2022). Recently, many studies reported that yogurt is considered one of the most important food products that can be compatible with other food ingredients. Besides, the addition of natural functional ingredients to yogurt has significantly gained consumers' acceptance because of the health benefits of both yogurt and natural functional ingredients (Table 1) (Ahmad et al. 2023; Basiri et al. 2022; Guadarrama-Flores et al. 2022; Huang et al. 2022; Rashwan et al. 2022; Shahein et al. 2022; Tami et al. 2022; Tang et al. 2022).

To summarize, natural functional ingredients such as fruit and fruit derivatives, vegetable and vegetable derivatives, cereals and cereals derivatives, seafood and seafood derivatives, and herp and spices contain many bioactive compounds which can improve the quality of yogurts.

Nutritional composition of functional yogurts

Traditional yogurt, live yogurt, set yogurt, stirred yogurt, Greek yogurt, yogurt drink, and frozen yogurt are some of the common names used to differentiate yogurt styles based on their production techniques, texture, taste, rheology, and sensory properties (Fig. 2) (Korkmaz et al. 2021; Li et al. 2021; Rashwan et al. 2022; Santos et al. 2022; Terpou et al. 2019). Set-type yogurt, stirred-type yogurt, and drinking-type yogurt are the three major types of yogurts available on the market, all of which have similar production practices (Arab et al. 2022; Gilbert and Turgeon 2021; Wang et al. 2020). The study of nutritional compositions of foods such as macronutrients, e.g., moisture or total solids, protein, fats, carbohydrates, and ash, micronutrients, e.g., vitamins and minerals, and bioactive components, e.g., phenolics, flavonoids, anthocyanins, and others are important to understand the health benefits and other nutrition properties of these foods (Rashwan et al. 2021). From a nutritional perspective, yogurt has a similar nutritional composition to milk from which it is made, which is widely perceived as healthy food as it contains proteins, carbohydrates, minerals, and vitamins (Ahmad et al. 2022; Buchilina 2021; Tami et al. 2022; Wang et al. 2023).

For instance, Oliveira et al. (2021) showed that the proximal composition of plain yogurt prepared from cow milk was an energy value of 49 kcal/100 g, carbohydrates 6.6 g/100 g, protein 5.7 g/100 g, total fat 0 g/100 g, dietary fiber 0 g/100 g, sodium 58 mg/100 g, and calcium 110 mg/100 g. Another study showed that normal buffalo stirred yogurt contained 12.74% of total solids, 3.88% of protein, and 0.92% of ash (Tami et al. 2022). Additionally, the protein, fat, lactose, total solids, and ash contents of yogurts from cow milk were 3.34, 3.83, 4.63, 14.25, and 0.98 g/100 g, from goat milk were 3.51, 4.15, 4.57, 12.23, and 0.65 g/100 g, and from camel milk were 3.57, 4.11, 4.37, 13.72, and 0.72 g/100 g, respectively (Wang et al. 2023). Furthermore, the proximate compositions of non-dairy yogurt prepared from sprouted tiger nut tubers were 88.59, 0.62, 0.69, 1.59, 1.30, 7.21, and 11.41% of moisture

Table 1 Functional compounds and health benefits of natural functional ingredients enriched yogurt.

Natural functional ingredients	Added part	Type of yogurt	Functional compounds	Biological activity	References
Fruits and their derivatives					
Strawberry	Fresh fruit	Stirred yogurt	Saturated fatty acids Monounsaturated fatty acids Polyunsaturated fatty acids Anthocyanins and minerals	Antioxidant activity Anti-inflammatory activity	Kowaleski et al. (2020)
Blueberry	Whole powder	Set yogurt	Phenolics, flavonoids Anthocyanins	Antioxidant activity	Lee et al. (2020)
Goldenberry	Fresh fruit juice	Yogurt drinks	Phenolics Carotenoids Ascorbic acid	Antioxidant activity Antihepatotoxic effect Protecting against hepatitis	Shahein et al. (2022)
Black mulberry	Mulberry puree	Stirred yogurt	Phenolics, flavonoids Anthocyanins	Antioxidant activity	Durmus et al. (2021)
Mulberry pomace	Powder	Stirred yogurt	Phenolic acids Anthocyanins	Antioxidant activity	Du et al. (2022)
Isabel grape	Fruit flour	Yogurt drinks	Flavanols and flavonols Phenolic acids Anthocyanins	Antioxidant activity Cardioprotective effect	Silva et al. (2022)
Grape pomace	Powder	Stirred yogurt	Anthocyanins, procyanidins Flavonol glycosides Phenolic acids and stilbenes	Antioxidant activity	Demirkol and Tarakci (2018)
Grape seeds	Extract powder	Stirred yogurt	Catechin and epicatechin Oligomers of proanthocyanidins	Antioxidant activity Antibacterial activity Anticancer activity	Tami et al. (2022)
M. dodecandrum Lour.	Whole powder	Stirred yogurt	Flavanols and flavonols Phenolic acids Anthocyanins	Antioxidant activity	Rashwan et al. (2022)
Monk fruit	Extract powder	Set yogurt	Phenolics Flavonoids Mogrosides	Antioxidant activity Antidiabetic activity Anti-obesity activity	Ban et al. (2020); Ban et al. (2022)
Purple passion fruit	Fresh fruit juice	Set yogurt	Phenolics Organic acids, vitamins	Antioxidant activity	Ning et al. (2021)
S. grosvenorii	Concentrated water extract	Set yogurt	Mogrosides Polyphenols Polysaccharides Volatile oil and vitamins	Antioxidant activity Antibacterial activity angiotensin-converting-enzyme inhibitory	Abdel-Hamid et al. (2020)
Hippophae rhamnoides L.	Whole powder	Frozen yogurt	Phenolics Prebiotics	Antioxidant activity Antibacterial activity	Terpou et al. (2019)
Wild pomegranate peel	Microencapsulated phenolic extract powder	Set yogurt	Phenolics Flavonoids	Antioxidant activity	Hamid et al. (2022)
Mango peel	Peel powder	Set yogurt	Phenolics and flavonoids Lignans and coumarins Carotenoids	Antioxidant activity Antibacterial activity Antidiabetic activity	Zahid et al. (2022)
Olive pomace	Pomace powder	Set yogurt	Dietary fiber and phenolics Hydroxytyrosol Unsaturated fatty acids	Antioxidant activity	Ribeiro et al. (2021)

Table 1 (continued)

Natural functional ingredients	Added part	Type of yogurt	Functional compounds	Biological activity	References
Apple pomace	Pomace powder	Stirred yogurt Yogurt drinks	Dietary fiber, polyphenols High-methoxyl (HM) pectin	Antioxidant activity	Wang et al. (2020)
Vegetables and their derivatives					
Spinach leaves	Aqueous extract (as a liquid)	Stirred yogurt	Phenolics Chlorophyll	Antioxidant activity Anti-inflammatory activity Anticarcinogenic	Wijesekara et al. (2022)
Red radish	Anthocyanin extract powder	Stirred yogurt	Anthocyanins	Antioxidant activity	Matus-Castillo et al. (2022)
Carrot waste	Encapsulated waste extract powder (beads)	Stirred yogurt	Phenolics β-carotene	Antioxidant activity Antihyperglycemic activity Anti-inflammatory activity	Šeregelj et al. (2021)
Tomato	Whole powder	Set yogurt	Vitamin C Lycopene Minerals	Antioxidative activity	Demirci et al. (2020)
Red cabbage	Juice Aqueous extract (as a liquid)	Stirred yogurt	Phenolics Flavonoids Anthocyanins	Antioxidative activity	Shalaby and Amin (2018)
Potato	Non-enzymatically and enzymatically hydrolyzed potato powder	Set yogurt	Proteins and minerals Flavonoids and phenolics	Antioxidative activity	Ahmad et al. (2023)
Purple sweet potato	Powder	Set yogurt	Phenolics Flavonoids Anthocyanins	Anti-obesity activity Cardioprotective effect	Khairani et al. (2020); Lin et al. (2012)
Cereals, legumes, and seeds					
Riceberry rice	Aqueous extract powder	Set yogurt	Phenolics Cyanidin-3-glucoside Peonidin-3-glucoside	Antioxidant activity Anti-inflammatory activity Antihyperlipidemic activity Anticancer	Anuyahong et al. (2020)
Navy bean	Bean milk	Set yogurt	Phenolics Peptides	Antioxidant activity Anti-inflammatory activity	Chen et al. (2019a)
Light red kidney bean	Bean milk	Set yogurt	Phenolics Peptides	Antioxidant activity Anti-inflammatory activity	Chen et al. (2019a)
Chia	Seeds powder	Stirred yogurt	Dietary fiber and minerals Saturated fatty acids Monounsaturated fatty acids Polyunsaturated fatty acids (ω-3 fatty acids)	Antioxidant activity Anti-inflammatory activity	Kowaleski et al. (2020)
Quinoa	Flour	Yogurt drinks	Free amino acids γ-Aminobutyric acid Polyphenols	Antioxidant activity Antidiabetic activity	Lorusso et al. (2018); Obaroakpo et al. (2020)
Flowers					
Asian pigeonwings	Aqueous extract (as a liquid)	Stirred yogurt	Phenolics Delphinidin	Antioxidant activity Anti-inflammatory activity	Wijesekara et al. (2022)

Table 1 (continued)

Natural functional ingredients	Added part	Type of yogurt	Functional compounds	Biological activity	References
Nyctanthes arbor-tristis L.	Aqueous flower extract (as a liquid)	Stirred yogurt	Phenolics	Antioxidant activity Antidiabetic activity Antiglycation activity	(Amadarshanie et al. 2022)
Hibiscus rosa-sinensis L.	Water extract (as a liquid)	Stirred yogurt	Phenolics Cyanidin-3-sophoroside	Antioxidant activity Anti-inflammatory activity	Wijesekara et al. (2022)
H. sabdariffa L.	Flowers marmalade	Stirred yogurt	Polyphenolic acid Flavonoids Anthocyanins	Antioxidant activity	Arslaner et al. (2021)
Rosa rugosa cv. Plena	Water extract powder	Set yogurt	Phenolics Anthocyanins Flavonoids Polysaccharides	Antioxidant capacity α-Amylase inhibition α-Glucosidase inhibition Proteolytic activity	Qiu et al. (2021)
Herbs and spices					
Coriander leaves	Methanol extract powder	Yogurt drinks	Polyphenols Alkaloids Flavonoids	Antioxidant activity	Shariati et al. (2020)
Moringa leaf	Water extract powder	Set yogurt	Phenolics	Antioxidant activity	Zhang et al. (2019)
M. parviflora leaves	Nanoemulsion of leaves extract (as a liquid)	Stirred yogurt	Polysaccharides Coumarins and polyphenols Vitamins and terpenes	Antioxidative activity Anti-inflammatory effect Antidiabetic activity	El-Naggar et al. (2020)
Argel leaf	Aqueous ethanol extract powder	Set yogurt	Phenolics	Antioxidant activity	Mohamed Ahmed et al. (2021)
Turmeric	Aqueous extract (as a liquid)	Stirred yogurt	Curcumin	Antioxidant activity Anti-inflammatory activity	Shalaby and Amin (2018); Wijesekara et al. (2022)
Cinnamon leaves	Water extract powder	Stirred yogurt	Phenolics Flavonoids	Antioxidant activity Anti-inflammatory activity	Tang et al. (2022)
Nutmeg	Aqueous extract (as a liquid)	Set yogurt	α-pinene and β-pinene p-cymene β-caryophyllene and carvacrol	Antioxidant activity Anti-inflammatory activity Antimicrobial	Shori (2022)
Black pepper	Aqueous extract (as a liquid)	Set yogurt	Lignans and alkaloids Flavonoids Aromatic compounds and amides	Antioxidant activity Anti-inflammatory activity Antimicrobial	Shori (2022)
White pepper	Aqueous extract (as a liquid)	Set yogurt	Lignans and alkaloids Flavonoids Aromatic compounds and amides	Antioxidant activity Anti-inflammatory activity Antimicrobial	Shori (2022)
Carob	Molasses	Stirred yogurt	Gallic acid Epigallocatechin gallate Minerals	Antioxidant activity Antibacterial activity Antitumor activity	Shalabi (2022)
Sacha inchi	Microencapsulated oil powder	Stirred yogurt	Polyunsaturated fatty acids	Antioxidant activity	Suwannasang et al. (2022)
Seafood					
Fish oil	Microencapsulatedω-3 fatty acids powder	Set yogurt	ω-3 fatty acids	Antidiabetic activity	Guadarrama-Flores et al. (2022)
Crassostrea gigas	Powder	Set yogurt	Peptides	Antioxidant activity Anti-inflammatory activity	Liu et al. (2022)

Table 1 (continued)

Natural functional ingredients	Added part	Type of yogurt	Functional compounds	Biological activity	References
Brown seaweeds	Aqueous ethanol extract powder	Stirred yogurt	Phenolics Flavonoids	Antioxidant activity	O'Sullivan et al. (2016)

Natural functional ingredients enriched yogurt showed several biological activities. Several food materials, such as fruits and their derivatives, vegetables and their derivatives, cereals, legumes, seeds, edible flowers, herbs, spices, and seafood, can be used as functional ingredients to produce functional yogurt. Natural functional ingredients can be incorporated in yogurt as several parts, such as fresh fruit, fresh vegetable, powder, or extract. Yogurt can be prepared as stirred yogurt, set yogurt, yogurt drinks, and frozen yogurt

content, crude protein, crude ash, crude fiber, crude fat, carbohydrates, and total solids, respectively (Ogundipe et al. 2021). Consequently, the above results indicate that the chemical composition of yogurt is affected by the milk source from which it was made.

On the other hand, the nutritional profile of yogurt will vary somewhat when natural functional ingredients such as ingredients of fruits, vegetables, cereals, and others are added. In recent years, yogurt and other dairy products have been used as carriers for functional food ingredients or nutraceuticals (Table 1) (Ahmad et al. 2022; Basiri et al. 2022; Rashwan et al. 2022). For example, stirred-type yogurt produced from commercial homogenized and pasteurized milk that was fortified with 1% skimmed milk powder contains 3.98, 5.35, 3.40, 13.99, and 0.70% of protein, carbohydrates, fat, total solids, and ash, respectively, after 1-day storage (Rashwan et al. 2022). These components decreased after storage of the yogurt for 7–21 days at 4 ± 2 °C, and this could be due to certain organisms in yogurt that utilizes protein and carbohydrates, and fat for their growth and metabolism (Rashwan et al. 2022). In the same study, the incorporation of *M. dodecandrum* Lour. fruit powder into yogurt significantly improved its chemical composition compared to the control. Besides, adding 1% *M. dodecandrum* Lour. fruit powder to yogurt increased the phosphorus, calcium, potassium, copper, and manganese contents by 2, 8, 24, 46.15, and 87.55%, respectively. These results may be due to *M. dodecandrum* Lour. fruit powder having a high content of total solids, carbohydrates, protein, and minerals, as well as reasonable amounts of fat, fiber, and ash (Rashwan et al. 2022).

Moreover, the incorporation of grape pomace powder into set-type yogurt improved total phenolic content 520.39-mg gallic acid equivalent/kg, and the total phenolic content was increased in yogurt as the grape pomace powder ratio increased (Demirkol and Tarakci 2018). Adding lyophilized microencapsulated phenolic extract powder (peel powder of wild pomegranate) by 2% to yogurt improved the contents of phenolic and flavonoid by 96.52 and 97.72%, respectively (Hamid et al. 2022). Besides, the chemical composition of stirred-type yogurt improved after the addition of carob molasses, where the total solids, fat, protein, and ash were changed from 15.57 to 24.05%, 4.29 to 3.37%, 5.33 to 6.27%, and 0.80 to 0.88%, respectively (Shalabi 2022).

In conclusion, the nutritional composition of yogurt improved significantly by adding natural functional ingredients. However, this improvement can be affected by the ingredients type, milk source, and duration of yogurt storage, as shown in Tables 1 and 2.

Quality attributes of functional yogurts

The quality characteristics of various yogurt types have gained great attention among consumers because of their ability to consume at any time. Color, pH, water-holding capacity, syneresis, and others are the easiest parameters that can directly indicate the quality of yogurt, even for the normal consumers. Therefore, improving the quality attributes of yogurt, such as pH, color, texture, structure, and other, has obtained the great interest of food scientists in recent years (Arab et al. 2022; Mohamed Ahmed et al. 2021; Rashwan et al. 2022; Wijesekara et al. 2022).

Color, pH, and titratable acidity

Color and acidity are the first characteristics perceived by the senses and are used by consumers for evaluating the quality of different food products' quality. Thus, they are important factors that can give an apparent quality indicator of yogurt enriched with fruit, where the consumers immediately relate color and acidity to overall product quality (Matus-Castillo et al. 2022; Shalaby and Amin 2018). Color properties have three main parameters, including L^* as lightness to darkness, 100 to 0, a^* as redness to greenness, red from 0 to 100, green from −80 to 0, and b^* as yellowness and blueness, yellow from 0 to +70, blue from −100 to 0. Besides, two additional parameters, including Hue angle ($H°$) and chroma (C) value, can be calculated from the previous three parameters, where $H°$ is the ratio of a^* and b^* and measures the property of color, and C value indicates the color intensity or saturation (Rashwan et al. 2022). Table 3 shows that fortification of yogurt with natural functional ingredients can add or restore

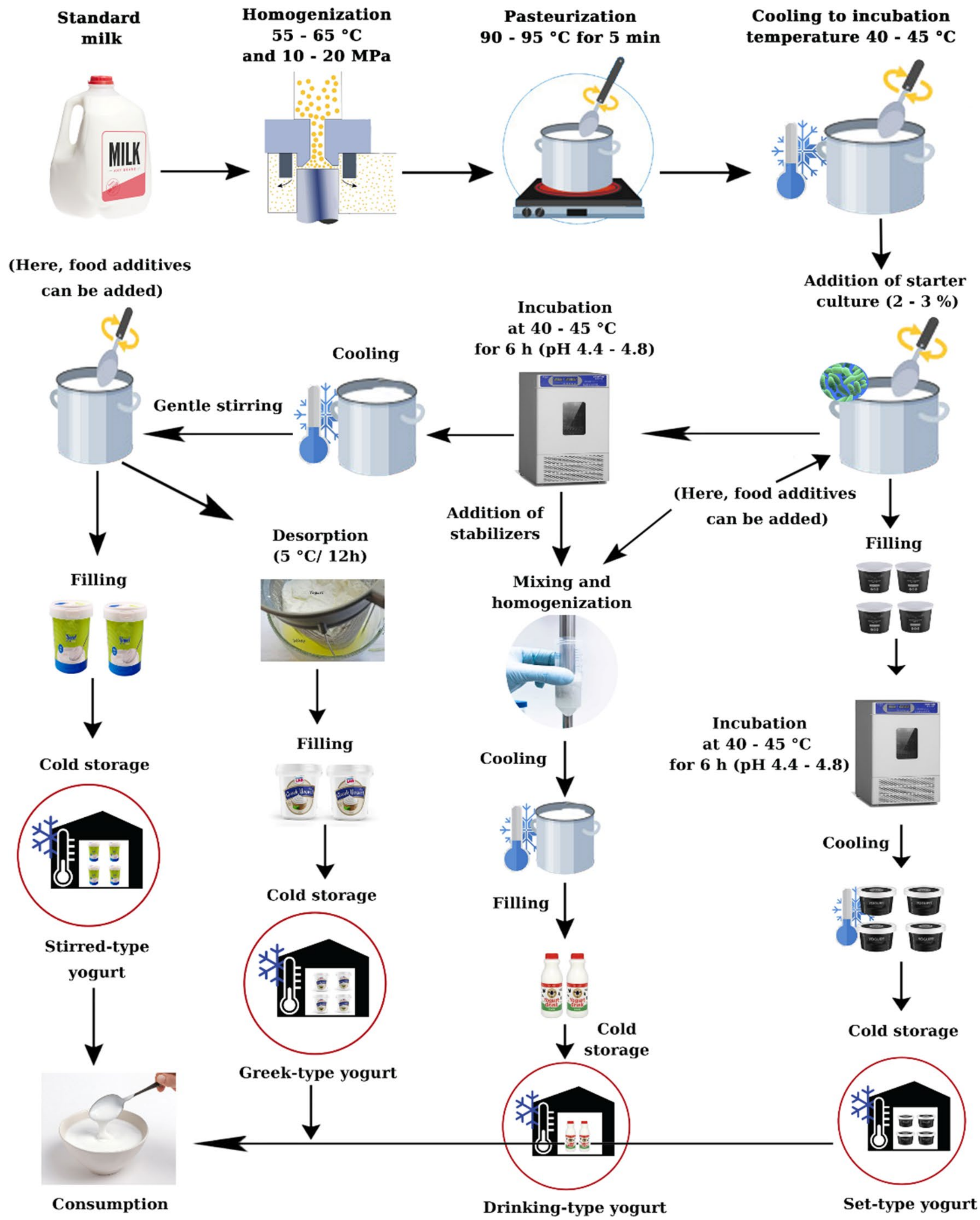

Fig. 2 Production steps of set-type yogurt, stirred-type yogurt, drinking-type yogurt, and Greek-type yogurt. Standard milk can be used to produce yogurt after the homogenization process to guarantee regular distribution of the fat globules in milk. Natural functional ingredients can be added to yogurt before pasteurization, after pasteurization, or after the fermentation process. Pasteurization is a process by which milk is heated to a specific temperature for a set period to kill pathogens as well as can assist in producing the protein network in yogurt. The incubation temperature must be 40–45 °C for yogurt bacteria to grow properly for 5–6 h till the pH reaches 4.4–4.8. Yogurt can be stored for 21 days under refrigeration conditions at 4 ± 2 °C. MPa and h refer to megapascal and hour, respectively

the color and control the acidity of the yogurt to boost its visual appeal and match consumer expectations (Basiri et al. 2022; Lee et al. 2020).

For instance, fortification of stirred-type yogurt with different concentrations of *M. dodecandrum* Lour. fruit powder significantly affected the color of yogurt, especially with

Table 2 Common nutritional composition and pH of plain yogurt and yogurt enriched with natural functional ingredients during cold storage (4 ± 2 °C).

Composition	Plain yogurt		Yogurt enriched with a natural functional ingredient		References
	1 day of cold storage	14 days of cold storage	1 day of cold storage	14 days of cold storage	
Total solids (%)	13.99–15.57	13.82–15.57	13.99–24.05	13.86–23.80	Arslaner et al. (2021), O'Sullivan et al. (2016), Rashwan et al. (2022), Shalabi (2022), Terpou et al. (2019)
Carbohydrates (%)	5.35–5.7	4.80–4.88	5.6–5.83	4.86–5.10	O'Sullivan et al. (2016), Rashwan et al. (2022), Shalabi (2022), Terpou et al. (2019)
Protein (%)	3.0–3.98	3.83–3.18	3.1–4.52	4.32–3.46	Arslaner et al. (2021), O'Sullivan et al. (2016), Rashwan et al. (2022), Shalabi (2022), Terpou et al. (2019)
Fat (%)	2.7–4.29	3.33–4.29	2.8–3.70	3.31–3.48	Arslaner et al. (2021), O'Sullivan et al. (2016), Rashwan et al. (2022), Shalabi (2022), Terpou et al. (2019)
Ash (%)	0.6–0.80	0.65–0.82	0.68–0.75	0.7–0.72	Arslaner et al. (2021), O'Sullivan et al. (2016), Rashwan et al. (2022), Shalabi (2022), Terpou et al. (2019)
Acidity	0.28–2.73	0.37–1.74	0.27–2.31	0.37–1.98	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022), Wijesekara et al. (2022)
pH	4.18–5.01	4.29–4.94	4.27–5.06	4.09–4.95	Huang et al. (2022), Rashwan et al. (2022), Shalabi 2022, Tang et al. 2022, Wijesekara et al. 2022)
Phosphorus (mg/Kg)	–	7335.94–8934.0	–	3569.11–9120.0	(Arslaner et al. 2021, Rashwan et al. 2022, Shalabi 2022)
Calcium (mg/Kg)	–	1255.23–10,712.0	–	739.24–11,650.0	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Magnesium (mg/Kg)	–	771.87–904.0	–	560.68–989.0	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Potassium (mg/Kg)	–	11,650.0–12,123.46	–	7274.5–15,512.0	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Sodium (mg/Kg)	–	3450.60–3692.0	–	1995.11–3533.0	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)

Table 2 (continued)

Composition	Plain yogurt		Yogurt enriched with a natural functional ingredient		References
	1 day of cold storage	14 days of cold storage	1 day of cold storage	14 days of cold storage	
Zinc (mg/Kg)	–	24.95–29.52	–	13.66–30.7	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Manganese (mg/Kg)	–	0.77–1.88	–	3.86–15.1	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Copper (mg/Kg)	–	0.28–0.85	–	0.24–0.52	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Iron (mg/Kg)	–	4.54–8.4	–	10.9–11.16	Arslaner et al. (2021), Rashwan et al. (2022), Shalabi (2022)
Total phenolics (mg GAE/100 g)	ND–0.16	ND–0.15	1.79–11.65	3.11–13.23	Anuyahong et al. (2020), Pelaes Vital et al. (2015), Rashwan et al. (2022)
Total flavonoids (mg RE/100 g)	ND–3.61	ND–3.61	5.3–51.98	4.64–50.59	Dantas et al. (2022), Rashwan et al. (2022), Shori et al. (2022)
Total anthocyanins (mg C3GE/100 g)	ND–0.04	ND–0.05	3.95–12.6	4.48–13.52	Anuyahong et al. (2020), Rashwan et al. (2022)

The addition of natural functional ingredients to yogurt increased the proximate composition of yogurt. Macro- and micro-elements in yogurt significantly improved with adding a natural functional ingredient. Yogurt enriched with natural functional ingredients showed a high polyphenols content compared to plain yogurt. Functional yogurt remains high nutritional composition during cold-storage time. These contents depend on the source of milk, type, and amount of added ingredients according to the references. Minerals content is based on dry weight, and other contents are based on the fresh weight of yogurt. ND refers to not detected, GAE refers to gallic acid equivalents, RE refers to rutin equivalents, and C3GE refers to cyanidin-3-glucoside equivalents

0.5 and 1% compared to the control. The addition of 1% weight/weight of *M. dodecandrum* Lour. fruit powder to yogurt decreased the L^* value 73.25, b^* value 3.16, and C value 7.74, as well as increasing a^* 3.16, and $H°$ values 65.92 compared to the control results L^* was 93.34, a^* was −2.99, b^* was 12.45, $H°$ was −76.48, and C was 12.80 after the 1 day of cold storage (Rashwan et al. 2022). The reason for this may be due to the dark red color and the presence of a high number of bioactive compounds in *M. dodecandrum* Lour. fruit powder that can significantly influence the yogurt color (Rashwan et al. 2022; Xu et al. 2023). Moreover, the addition of grape pomace powder to set-type yogurt using different ratios of 1, 3, and 5% significantly improved the yogurt color. Among all concentration, 5% grape pomace powder showed a good color of yogurt even at the end of the storage period (Demirkol and Tarakci 2018).

The pH and titratable acidity are two related parameters for food analysis that is correlated with acidity, and each provides insights into food and food product quality. For instance, pH can evaluate the ability of microorganisms to grow in a specific food, while titratable acidity is a better predictor than pH of how organic acids in food influence flavor (Chen et al. 2017). Incorporating natural functional ingredients with yogurts can positively or negatively change the pH and titratable acidity positively or negatively based on the type and amount of ingredients as well as storage time, as shown in Table 3. For instance, grape pomace powder-fortified yogurt had a relatively higher acidity of 0.78–0.93% initially, and this could be because of the presence of some organic acids in grape pomace, which can increase the yogurt acidity (Demirkol and Tarakci 2018).

Moreover, supplementing buffalo milk yogurt with water extract from monk fruits by the ratios of 1% and 2% accelerated fermentation and reduced the pH of yogurt after cold storage for 24 h. The reduction of yogurt pH after the incorporation of monk fruit extract could be attributed to enhancing bacterial growth and increasing the fermentation process, as well as monk fruit extract may be contained organic acids, hence, decreasing the pH of yogurt (Abdel-Hamid et al. 2020). The lactic acid bacteria metabolic enhancement was due to various phytochemical components, such as phenolic compounds, flavonoids, and organic acids (Rashwan et al. 2022). Besides, Mohamed Ahmed et al. (2021) found that argel leaf extract powder-fortified yogurts showed lower

Table 3 Physicochemical properties of yogurt fortified with different natural functional ingredients.

Samples	Yogurt type	Cold-storage period (4 ± 2 °C)	Ratio	Parameters: Color								References
				L^*	a^*	b^*	pH	TA (%)	WHC (%)	Syneresis (%)	LAB (log CFU/g)	
Grape pomace powder	Set yogurt	21st days	Control	91.56	−1.73	9.21	4.02	0.88	68.01	31.99	8.80	Demirkol and Tarakci (2018)
			3% (w/w)	58.29	6.42	6.20	3.94	1.02	65.20	34.80	8.40	
Moringa extract powder	Set yogurt	1st day	Control	89.74	−7.99	9.83	4.26	–	15.00	25.00	8.88	Zhang et al. (2019)
			0.2% (w/v)	89.23	−8.77	15.5	4.18	–	17.00	21.00	7.35	
Phycocyanin powder from *Spirulina platensis* bacteria	Stirred yogurt	21st days	Control	72.45	−1.90	7.48	4.59	–	69.13	30.87	6.70	Mohammadi-Gouraji et al. (2019)
			4% (w/w)	62.59	−6.45	−2.38	4.87	–	69.76	30.24	7.00	
Riceberry rice extract powder	Set yogurt	21st days	Control	43.34	−1.24	8.65	4.65	0.58	91.64	8.36	2.07	Anuyahong et al. (2020)
			0.25% (w/w)	19.06	9.86	4.72	4.63	0.61	93.56	6.44	2.10	
Hot break tomato powder	Set yogurt	7th days	Control	89.72	−3.43	6.92	4.33	0.31	54.50	45.50	8.60	Demirci et al. (2020)
			1% (w/v)	83.95	0.94	13.40	4.54	0.29	58.50	41.50	8.20	
Cold break tomato powder	Set yogurt	7th days	Control	89.72	−3.43	6.92	4.33	0.31	54.50	45.50	8.60	Demirci et al. (2020)
			1% (w/v)	79.74	4.57	17.37	4.53	0.31	52.5	47.50	8.40	
Monk fruit sweetener	Yogurt drinks	21st days	Control	94.00	−0.91	7.80	4.40	0.83	–	–	6.50	Buchilina 2021
			0.42 g/L	93.00	−0.80	8.00	4.30	0.82	–	–	7.00	
Argel leaf extract powder	Set yogurt	21st days	Control	94.69	−1.84	16.71	4.30	0.70	51.00	47.00	9.00	Mohamed Ahmed et al. (2021)
			0.2% (w/v)	92.64	−1.49	16.58	4.19	0.75	49.00	50.00	9.40	
Purple passion fruit juice	Set yogurt	14th days	Control	78.70	−0.45	6.70	4.50	–	96.00	4.00	7.89	Ning et al. (2021)
			5% (v/v)	74.00	−0.29	7.93	4.45	–	98.20	1.80	7.53	
Tapioca starch powder	Yogurt-like product from coconut milk	14th days	Control	79.68	–	–	4.52	–	84.00	16.00	6.17	Pachekrepapol et al. (2021)
			2% (w/w)	78.26	–	–	4.49	–	88.00	12.00	5.96	
Edible rose flower extract powder	Set yogurt	21st days	Control	89.92	−4.13	9.07	4.11	1.12	26.00	72.00	–	Qiu et al. (2021)
			0.5% (w/w)	83.47	1.48	11.54	4.20	0.97	31.00	69.00	–	
Pilosocereus gounellei flour	Stirred yogurt	14th days	Control	82.92	−1.88	7.46	4.42	0.54	–	–	7.25	Dantas et al. (2022)
			1% (w/w)	70.10	−2.03	8.72	4.43	0.79	–	–	7.40	
Carrot soluble dietary fiber powder	Set yogurt	21st days	Control	50.40	2.30	4.90	4.32	1.09	42.10	57.90	–	Dong et al. (2022)
			0.67% (w/v)	48.30	9.50	11.9	4.14	1.18	53.30	46.70	–	
Quinoa milk	Soy milk yogurt	21st days	Control	58.82	0.28	11.82	4.18	0.73	38.70	61.3	26.60	Huang et al. (2022)
			2% (v/v)	54.22	0.05	11.41	4.01	0.69	43.80	56.20	26.47	
M. dodecandrum Lour. fruit powder	Stirred yogurt	21st days	Control	93.71	−3.12	12.54	4.27	0.37	74.07	25.93	–	Rashwan et al. (2022)
			1% (w/w)	74.68	3.11	9.68	4.27	0.39	75.54	21.52	–	
Carob molasses	Stirred yogurt	14th days	Control	60.43	4.23	7.83	4.29	1.12	65.00	35.00	10.70	Shalabi (2022)
			10% (v/v)	53.67	2.70	9.33	4.18	1.46	60.00	40.10	10.23	
Peel and seeds of Isabel grape powder	Probiotic stirred yogurt	14th days	Control	35.48	−0.86	1.40	4.32	0.74	–	–	8.30	Silva et al. (2022)
			20% (w/v)	24.55	5.25	−1.46	3.91	0.85	–	–	8.50	

Table 3 (continued)

Samples	Yogurt type	Cold-storage period (4 ± 2 °C)	Ratio	Parameters									References
				Color			pH	TA (%)	WHC (%)	Syneresis (%)	LAB (log CFU/g)		
				L^*	a^*	b^*							
Sacha inchi oil powder	Stirred yogurt	21st days	Control	87.90	−2.00	7.40	4.00	1.25	62.50	37.50	–		Suwannasang et al. (2022)
			1% (w/w)	88.20	−2.00	7.40	3.90	1.24	62.00	38.00	–		
Microencapsulated sacha inchi oil powder	Stirred yogurt	21st days	Control	87.90	−2.00	7.40	4.00	1.25	62.50	37.50	–		Suwannasang et al. (2022)
			1% (w/w)	87.70	−2.10	7.90	3.80	1.35	67.50	32.50	–		
Anthocyanin from hibiscus	Probiotic stirred yogurt	14th days	Control	88.00	−0.83	15.00	4.94	1.74	70.98	29.02	13.94[a]		Wijesekara et al. (2022)
			10% (w/v)	81.00	2.67	12.00	4.95	1.59	60.80	39.20	13.77[a]		
Curcumin from turmeric	Probiotic stirred yogurt	14th days	Control	88.00	−0.83	15.00	4.94	1.74	70.98	29.02	13.94[a]		Wijesekara et al. (2022)
			4% (w/v)	87.00	−3.00	31.00	4.87	1.98	67.97	32.03	13.69[a]		
Chlorophyll from spinach	Probiotic stirred yogurt	14th days	Control	88.00	−0.83	15.00	4.94	1.74	70.98	29.02	13.94[a]		Wijesekara et al. (2022)
			6% (w/v)	85.00	−1.67	20.00	4.89	1.62	67.85	32.15	14.90[a]		
Anthocyanin from blue pea	Probiotic stirred yogurt	14th days	Control	88.00	−0.83	15.00	4.94	1.74	70.98	29.02	13.94[a]		Wijesekara et al. (2022)
			4% (w/v)	74.00	−2.83	2.00	4.87	1.80	63.56	36.44	13.99[a]		

Natural functional ingredients can be added to yogurt in various concentrations. The concentration of natural functional ingredients is based on the concentration of the bioactive compounds in food additives. Adding natural functional ingredients to yogurt improved the color even during the cold-storage period (4 ± 2 °C). The number of lactic acid bacteria in yogurt improved after adding natural functional ingredients due to the presence of nutrients. Physicochemical properties of yogurt, including pH, titratable acidity, and water-holding capacity, markedly improved with adding functional ingredients. Yogurt fortified with functional ingredients showed lower syneresis than plain yogurt. L^* refers to lightness to darkness (100–0), a^* refers to redness (0–100) to greenness (− 80 to 0), b^* refers to yellowness (0–70) to blueness (− 100 to 0), LAB refers to number of lactic acid bacteria, CFU refers to colony-forming unit, WHC refers to water-holding capacity, TA refers to titratable acidity, w refers to weight, and v refers to volume.

[a]refers to log 10 CFU/mL

pH values and higher acidity than the controls throughout the whole storage period. The low pH and high acidity of the argel leaf extract powder-fortified yogurts may be because of the presence of fermentable components in argel leaf extract powder that was metabolized by lactic acid bacteria, resulting in the production of organic acid (Mohamed Ahmed et al. 2021).

To summarize, adding natural functional ingredients to yogurt significantly improved the color, pH, and titratable acidity of fortified yogurt compared to plain yogurt. Besides, yogurt with natural functional ingredients has a good quality during storage time.

Water-holding capacity, syneresis, and viscosity of yogurts

Water-holding capacity, syneresis, and apparent viscosity (τ is shear stress (Pa) and $\dot{\gamma}$ is a shear rate (s^{-1})) are important physical properties that can determine the quality of yogurt because these characteristics can limit the shelf-life and acceptability of products. Water-holding capacity is one of the most important physical properties that contribute to the curd stability of yogurt texture, which expresses the ability of yogurt to retain its own or added water against gravity or external force, including centrifugation, heating, or pressure (Chen et al. 2023; Demirci et al. 2020; Gyawali and Ibrahim 2016). Several factors, such as milk composition (protein and/or fat globules), food additives, starter culture, and processing conditions, can affect the water-holding capacity of yogurt. Thus, fortified yogurt with natural functional ingredients can increase or decrease its water-holding capacity (Table 3) based on the water-holding capacity of natural functional ingredients.

For example, incorporating water extract powder from moringa leaf in yogurt decreased syneresis values and increased water-holding capacity, suggesting improved viscosity. These results could be because of some interactions between the yogurt proteins and components of moringa extract, where the gel matrix of yogurt seemed to increase with the addition of moringa extract, thereby being able to hold more yogurt serum (Zhang et al. 2019). In which the polyphenols and yogurt protein reaction could change the structure of protein and improve the affinity of protein, thereby promoting protein cohesion (Kwon et al. 2019). Moreover, set-type yogurt containing 0.5% cold break tomato powder showed higher water-holding capacity values of 55.40 g/kg than the control 54.50 g/Kg. This effect can arise due to the hygroscopic behavior of tomato powders that can retain a high amount of water (Demirci et al. 2020). On the other hand, the water-holding capacity of stirred-type yogurt containing carob molasses significantly decreased with increasing concentration of carob molasses (Shalabi 2022). However, the water-holding capacity of yogurts significantly improved after the addition of natural functional ingredients.

Furthermore, syneresis is an important index for assessing yogurts quality, which indicates the balance between attraction and repulsion forces within the network of casein and the rearrangement capacity of the network bond (Arab et al. 2022). The addition of 0.13–0.5% riceberry rice extract powder to yogurt caused a significant reduction in the syneresis of yogurt. A decrease in syneresis by riceberry rice extract powder contributes to an increase in the entrapment of water within the gel network, resulting in the reduction of serum release from yogurt. The explanation of this effect occurring might be because of the presence of polyphenols in riceberry rice extract powder. These polyphenols interacted with protein and led to reduced syneresis of yogurt (Anuyahong et al. 2020). Additionally, prepared yogurt-like products made from coconut milk with the addition of 2.0% tapioca starch resulted in a significantly lower degree of syneresis compared to the control. The initial syneresis degree of yogurt-like products with 2.0% tapioca starch was 19.34% and reduced to 9.52% by the end of storage, while the initial syneresis degree of the control sample was 23.54% and reduced to 13.10% by the end of storage (Pachekrepapol et al. 2021).

Besides, fortification of commercial coconut yogurt with combined thickener and a gelling agent such as starch and pectin achieved a much lower syneresis level ~0.7% (Grasso et al. 2020). The reduction in syneresis degree may be attributed to an increase in water-holding capacity because of the swelling property of starch and pectin, which can lead to substantial quantities of water retained in the yogurt matrix (Wong et al. 2020). Moreover, the supplement of yogurt by natural functional ingredients improved its viscosity. For instance, yogurt η significantly improved via incorporating argel leaf extract powder in yogurt, where the viscosity improved with increasing argel leaf extract powder concentrations compared to plain yogurt. The improvement of yogurt η after adding argel leaf extract powder may be due to the interaction between argel leaf extract powder compounds, including phenolic compounds and the proteins, with yogurt proteins, resulting in the development of a firmer three-dimensional network and viscous gels (Mohamed Ahmed et al. 2021). Additionally, fortified stirred-type yogurt with 10% carob molasses showed high viscosity 175.33 (mPas) than the control 55.73 (mPas), even after storage for 14 days at refrigeration conditions 158.80 and 97.33 mPas, respectively (Shalabi 2022).

Another study showed that the viscosity of set-type yogurts increased from 0.48 Pa•s up to 1.76 Pa•s after adding 1.25% weight/volume of insoluble soybean fiber. This improvement in yogurts viscosity with the addition of insoluble soybean fiber has been attributed to the fact that it is a potential thickening agent because of its unique viscous property in the aqueous phase. Another reason for increasing the viscosity is that the increased concentration of the substance decreased the free space of motion, inevitably promoting collision, or entanglement during shear. Besides, the enhanced bond between water molecules and gel matrix tended to have an increased viscosity (Chen et al. 2023). In contrast, the viscosity of phycocyanin powder-enriched yogurts was lower than that of plain yogurt. This reduction of viscosity is probably because of the changes in the microstructure of yogurt gel after adding phycocyanin which has caused a break-up yogurt gel network, thereby reducing surface tension and causing the decrease in viscosity (Mohammadi-Gouraji et al. 2019).

To summarize, the water-holding capacity and apparent viscosity of yogurt significantly increased by adding natural functional ingredients even during the storage period compared to normal yogurt, as well as adding natural functional ingredients to yogurt reduced syneresis due to the unique composition of the food additivities.

Microstructure, texture, and fat globules of yogurts

Yogurt constitutes a mixture of biopolymers such as proteins, polysaccharides, and fats. The texture, sensory properties, fat globules, and storage stability can be affected by the microstructure of milk protein gels and their rheological properties (Wang et al., 2023). The microstructure of yogurt is formed from a three-dimensional network of casein micelles aggregates, where the globular shape is observable and interspaced by void zones (Gilbert and Turgeon 2021; Gyawali and Ibrahim 2016). The addition of natural functional ingredients to yogurts can improve their microstructure, as shown in Fig. 3. For instance, yogurt without *Pleurotus ostreatus* extract powder exhibited a continuous ramified network, with big void spaces, which may cause a massive structural rearrangement and contraction of the protein network during storage. All these effects almost disappeared when low-fat yogurt was supplemented with 0.75% or 1% aqueous extract powder of *P. ostreatus*, where the microstructure of yogurt became more compact (Pelaes Vital et al. 2015).

Furthermore, Rashwan et al. (2022) showed that fortifying stirred-type yogurt with various concentrations of *M. dodecandrum* Lour. fruit powder significantly improved

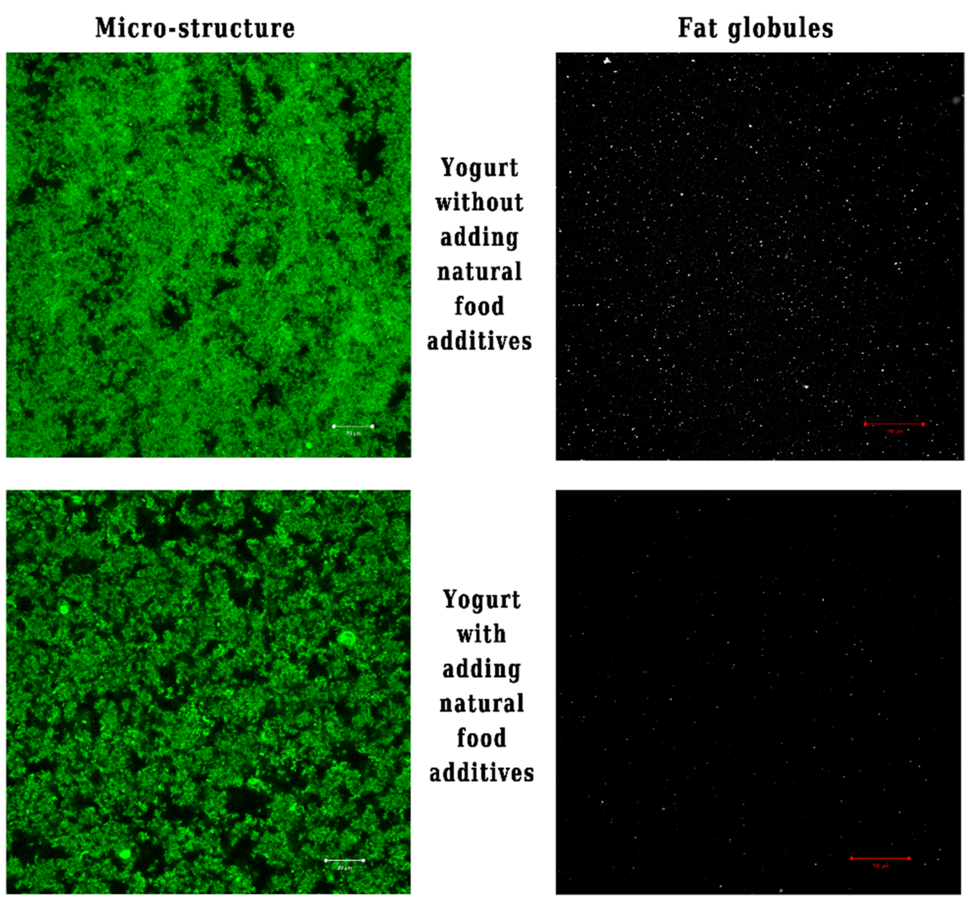

Fig. 3 Confocal laser scanning microscopy of microstructures and fat globules of stirred-type yogurt without and with adding *M. dodecandrum* Lour. fruit powder after the 7th day of storage at 4 ± 2 °C (unpublished data from our laboratory work). The fat globules work as structure modifiers and affect the rheological characteristics of the composite gels, including yogurt. The incorporation of natural functional ingredients in yogurt markedly reduced the escape of fat globules from the yogurt network to the supernatant (under centrifugation) compared to normal yogurt. Fortification of yogurt with natural functional ingredients markedly improved the structure of functional yogurt compared to the control. Adding natural functional ingredients caused the formation of smaller pores and channels in the yogurt structure, as well as more compact and even protein aggregates than plain yogurt

the microstructure of stirred-type yogurt compared to the yogurt control. Besides, at 0.25%–0.50% insoluble soybean fiber addition, set-type yogurt showed a more homogeneous network, and fewer open serum channels compared to plain yogurt were favorable to water binding in the gel network (Chen et al. 2023). This phenomenon is attributed to the fact that some of natural functional ingredients can work as a thickening agent; thus, they can improve the microstructure of yogurt. Additionally, natural functional ingredients may act as a spring anchor to the network of casein micelles, which provides higher water-binding capacity, improving the microstructure of yogurt. Adding natural functional ingredients may also cause the formation of smaller pores and channels in the microstructure of yogurt, and a more compact structure and even protein aggregates than those of plain yogurt (Brückner-Gühmann et al. 2019; Chen et al. 2023; Dong et al. 2022; Rashwan et al. 2022; Santos et al. 2022; Wang et al. 2019).

Moreover, the texture of yogurts, such as firmness, consistency, cohesiveness, and viscosity index, can be maintained and improved by adding natural functional ingredients that can contribute to the yogurt texture through the gelling-texturizing capability of natural functional ingredients (Pachekrepapol et al. 2021; Wang 2020). The addition of 1% apple pomace powder to set-type yogurt and 3% to stirred-type yogurt increased firmness, cohesiveness, and viscosity index, as well as the yogurts with 1% and 3% apple pomace powder, were significantly firmer than the yogurt control. Due to the presence of dietary fibers in apple pomace powder, the texture of yogurts was improved, where the dietary fibers interacted with the casein matrix, thus altering the milk gelation process (Wang et al. 2019; Wang et al. 2020). In addition, yogurt containing oat protein concentrate of 6.2% weight/weight improved strength in texture analysis of yogurt due to the increase in the dry matter yogurt (Brückner-Gühmann et al. 2019). Supplemented stirred-type yogurt with 0.5% and 1% weight/weight of *M. dodecandrum* Lour. fruit powder significantly increased the firmness compared to the sample control (Rashwan et al. 2022). This could be due to the increase in the total solids of yogurt after incorporating *M. dodecandrum* Lour. fruit powder. Besides, the interaction of *M. dodecandrum* Lour. fruit powder components, including fibers and polyphenols, with the protein matrix of yogurt can increase the yogurt's density and rigidity (Rashwan et al. 2022).

On the other hand, the firmness, consistency, cohesiveness, viscosity, and gel strength of yogurt were decreased with the addition of rice bran. These alterations might result due to the changes in yogurt microstructure induced by rice bran, where the gel network of rice bran-fortified yogurt became looser and hollower, which might make the yogurt gel more fragile (Wu et al. 2023). The fat globules work as structural modifiers and affect the rheological characteristics of yogurt. Thus, the loss of fat globules from yogurt to the whey can reduce the quality of yogurt; hence, fortifying yogurt with natural functional ingredients can act as membrane stabilizers for fat globules in yogurt, decreasing the escape of fat globules to the whey and thereby rupturing the network of yogurt (Fig. 3) (Mary et al. 2022; Rashwan et al. 2022). For example, the enrichment of set-type yogurt by non-enzymatically hydrolyzed guar gum and orange peel fiber improved the stability of fat globules in yogurt, and a few fat globules escaped to the supernatant under high centrifugal force (Mary et al. 2022). Moreover, the incorporation of *M. dodecandrum* Lour. fruit powder in stirred-type yogurt noticeably reduced the fat globules escaping from the yogurt network to the supernatant. This effect might be attributable to the increase in protein content, total solids, and polyphenol content in yogurt after adding *M. dodecandrum* Lour. fruit powder, reducing the separation of fat globules from yogurt (Rashwan et al. 2022).

In conclusion, the enrichment of yogurts with optimal concentrations of natural functional ingredients markedly improved the microstructure and texture of yogurts as well as reduced the loss of fat globules from yogurts. However, increased natural functional ingredients concentrations beyond the required concentration can cause the escape of fat globules from yogurts to supernatant and breakdown the yogurt microstructure and texture.

Microbiological characteristics

Living microorganisms are also known as probiotics that benefit human beings through their metabolism products. Normally, probiotics are added during the preparation of yogurt to cause fermentation of some milk contents, thus, providing therapeutic benefits such as alleviation from lactose intolerance, reduction of cholesterol, enhanced microbial balance in the digestive tract, and biological activities (Li et al. 2021; Pelaes Vital et al. 2015). *Lactobacillus rhamnosus*, *Lactobacillus casei*, *Lactobacillus plantarum*, *L. delbrueckii* subsp., and *S. thermophilus* are the main species most used to produce yogurt (Shori et al. 2022). The concentration of live bacteria should be not less than 10^6 or 10^7 colony-forming unit/gram to provide health benefits of fermented milk; for example, in the USA and European countries, the presence of live yogurt culture $> 10^6$ colony-forming unit/milliliter is made essential in yogurt preparations (Wijesekara et al. 2022). Consequently, the availability of probiotics in yogurt can be increased by the addition of natural functional ingredients (Table 3), where natural functional ingredients contain some components, including essential amino acids, essential fatty acids, vitamins, minerals, and others, that can assist to increase the growth of bacteria (Mohamed Ahmed et al. 2021; Mohammadi-Gouraji et al. 2019; Wijesekara et al. 2022).

Preparation of yogurt with 1% xique-xique flour increased the number of viable cells of *S. thermophilus* to 7.33 log colony-forming unit/gram up to 14 days of refrigerated storage compared to the control 7.29 log colony-forming unit/gram (Dantas et al. 2022). The increase in viable counts of *S. thermophilus* after the addition of xique-xique flour may be due to the presence of a considerable amount of carbohydrates, organic acids, and flavonoids, which can provide the nutrients for bacteria growth, as well as the availability of favorable conditions for bacterial metabolic activity such as pH and acidity (Dantas et al. 2022). Moreover, enrichment of stirred-type yogurt with anthocyanins-rich extract (blue pea) improved the number of viable cells of probiotics, including *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus*, and *Bifidobacterium animalis* subsp. from 13.94 logs colony-forming unit/milliliter (control) to 13.99 logs colony-forming unit/milliliter (treatment) after 14 days of refrigerated storage. This increase may be attributed to anthocyanins facilitating the metabolic rate and growth of starter cultures (Wijesekara et al. 2022). However, the addition of an aqueous extract of curcumin to stirred-type yogurt reduced the number of viable cells of probiotics, and this effect could be due to the antimicrobial properties of turmeric and, therefore, adversely affects the growth of starter culture (Wijesekara et al. 2022).

To summarize, yogurt fortified with natural functional ingredients showed a high number of viable cells compared to yogurt without food additives. However, some of the natural functional ingredients, such as curcumin, decreased the number of viable cells due to the antibacterial properties of curcumin.

Sensory evaluation of yogurts

The sensory attributes of yogurts, including color, odor, appearance, flavor, texture, and overall acceptance, are important criteria to verify the general acceptability of products by consumers and their commercial success (Huang et al. 2022; Pachekrepapol et al. 2021). Commonly, sensory assessment of any product, not only yogurt is completely entirely up to the taste and preference of the consumer. However, the quality of the product also plays an important role in attracting the acceptability of consumers (Arslaner et al. 2021; Korkmaz et al. 2021). Hence, supplementing yogurt with natural functional ingredients can encourage the consumer to accept the product due to the high nutritional value of these additives, such as bioactive compounds, proteins, vitamins, minerals, and other as well as natural functional ingredients are natural flavorings and colorants (Matus-Castillo et al. 2022; Oliveira et al. 2021; Qiu et al. 2021; Wijesekara et al. 2022; Yang et al. 2021). For instance, the sensory evaluation of yogurt-like products from coconut milk indicated that adding tapioca starch from 1.0% led to higher liking scores, especially texture attributes (Pachekrepapol et al. 2021).

Besides, strawberry- or vanilla-enriched yogurt showed high flavor and overall acceptance because of the presence of several flavor compounds in both strawberry and vanilla, including propylene glycol, ethyl alcohol, and natural flavoring (Oliveira et al. 2021). The addition of honey with strawberry flavor to soy yogurt also increased sensory acceptance of soy yogurt compared to plain yogurt (Rahmatuzzaman Rana et al. 2021). Additionally, the incorporation of Isabel grape ingredients in probiotic goat milk yogurts caused a greater perception of sweetness. This sweetness effect, combined with the natural aroma from Isabel grape ingredients, probably assisted in facilitating the consumption of these products by consumers unfamiliar with goat milk products by decreasing the perception of acidity and goat milk aroma (Silva et al. 2022).

To summarize, the supplementation of yogurt with natural food additives improved the sensory evaluation of yogurt due to the presence of the flavor compounds in natural food additives, especially in strawberries, vanilla, herbs, and spices.

Potential biological activity of functional yogurts

Recently, developing yogurt as a functional food has garnered increasing interest from researchers due to the health importance of yogurt, where the production of functional yogurt is increasing day by day, which reached about 292,000 tons in 2019 compared to 269,000 in 2018, as demonstrated in Fig. 4 (FAOSTAT 2022).

Generally, plain yogurts can show health benefits such as antioxidant activity, enhanced vitamin and mineral absorption, as well as boost the immune system (Rashwan et al. 2022; Šeregelj et al. 2021). However, due to the absence of many nutrients such as phenolics, flavonoids, anthocyanins, iron, and others from plain yogurt, the other biological activity, such as antidiabetic, antiobesity, antimicrobial, and others, are limited (Saini et al. 2021; Silva et al. 2022; Wu et al. 2023). Therefore, the enrichment of yogurts with natural functional ingredients can enhance the biological activities of yogurt because natural functional ingredients can provide many bioactive compounds, as shown in Table 1 and Fig. 5. Additionally, the matrix of yogurt could contribute to the stability of some phenolic compounds, especially catechin, epicatechin, and kaempferol, resulting enhance the bioavailability of these components, thus, increasing their bioactivity (Demirkol and Tarakci 2018; Rashwan et al. 2022). Besides, lactic acid bacteria can convert some compounds, such as procyanidins and phytate, during their metabolism

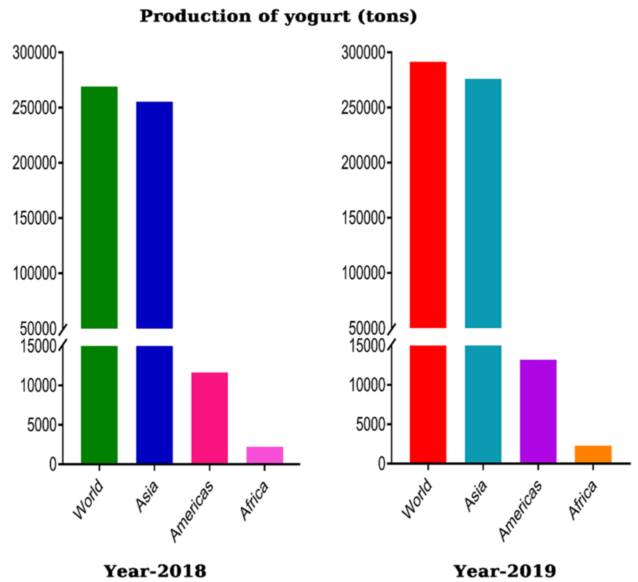

Fig. 4 Worldwide yogurt production in 2018 and 2019, according to food and agriculture organization corporate statistical database (FAOSTAT 2022). The production of yogurt is increasing day by day, which reached about 292,000 tons in 2019 compared to 269,000 tons in 2018. The production rate of yogurt increased by 4% from 2018 to 2019. Asia has the highest yogurt production in both years 2018 and 2019. Africa has the lowest yogurt production in both years 2018 and 2019

to other forms with high bioactivity (Rashwan et al. 2021; Silva et al. 2022; Sorour et al. 2017).

Antioxidant activity

Plain yogurt can exhibit antioxidant properties, whereas fermentation of yogurt (milk) can produce several amino acids and small peptides with antioxidant effects. Moreover, the reducing sugars, fatty acids, oligosaccharides, and lactic acid bacteria that are presented in yogurt can act as reducing agents and exhibit antioxidant properties (Silva et al. 2022; Wang et al. 2023). Nevertheless, the inclusion of natural functional ingredients in yogurts can play a crucial role in enhancing and increasing the antioxidant activity of yogurts because of the presence of a high number of antioxidant components such as polysaccharides, phenolics, flavonoids, anthocyanins, and others (Table 1) (Ahmad et al. 2023; Du et al. 2022; Lee et al. 2020; Shori 2022; Shori et al. 2022).

For instance, the study on the antioxidative activity of the yogurts by the 2,2-diphenyl-1-picrylhydrazyl method showed that the reduction of 2,2-diphenyl-1-picrylhydrazyl radicals by soy yogurts (control) and rice bran oil-sesame oil incorporated soy yogurt on 0 days was found to be 12.59% and 32.26%, respectively, and on 28 days was 13.25% and 33.18% (Sengupta et al. 2016). The reason for the increased antioxidant activity of soy yogurt after adding rice bran oil-sesame oil is the high level of antioxidant components presented in rice bran oil-sesame oil enriched soy yogurt than in soy yogurt (control), which could react rapidly with 2,2-diphenyl-1-picrylhydrazyl radicals and reduce almost all 2,2-diphenyl-1-picrylhydrazyl radical molecules corresponding to available hydroxyl groups. In which the soy yogurt enriched with rice bran oil-sesame oil significantly exhibited high polyphenolic content on 0 days and 28 days was 4800 and 4816 µg/100 g, respectively, compared to the soy yogurt control was 1205 µg/100 g (Sengupta et al. 2016). Probiotic yogurts with 2% *Siraitia grosvenorii* fruit extract showed significantly higher antioxidant activities at 78.21% and 91.16% according to the 2,2-diphenyl-1-picrylhydrazyl and 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) methods, respectively, compared with that of the control probiotic yogurt 29.50 and 48% (Abdel-Hamid et al. 2020).

In this context, the antioxidant activity of probiotic set-type yogurt increased upon adding the fruit extracts may be due to the high contents of polyphenols, mogroside, and vitamin C in this fruit (Abdel-Hamid et al. 2020). Besides, the measurement of antioxidant activity of yogurt enriched with *Hibiscus sabdariffa* L. flowers marmalade 20% using two methods, including copper (II) reducing antioxidant capacity and 2,2-diphenyl-1-picrylhydrazyl assay showed that enriched yogurt had higher antioxidant activity 15.03 and 26.73 mg trolox equivalent/100 g, respectively, than yogurt control 4.88 and 5.92 mg trolox equivalent/100 g, respectively (Arslaner et al. 2021). *M. dodecandrum* Lour. fruit powder-enriched stirred-type yogurt also showed higher antioxidant activity than the control sample, even during the storage period (Rashwan et al. 2022). The high content of phytochemicals found in *M. dodecandrum* Lour. fruit powder, including dietary fiber and polyphenol contents that are known for their antioxidant properties, was most likely responsible for the increased antiradical ability of the *M. dodecandrum* Lour. fruit powder-containing yogurt (Rashwan et al. 2022; Xu et al. 2023).

Furthermore, adding 0.5% grape seed extract to buffalo stirred-type yogurt significantly increased the inhibition percentage of the 2,2-diphenyl-1-picrylhydrazyl radical and 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radicals by 26.81% and 52.38% in the treated sample compared to 16.02 and 9.29% in the control (Tami et al. 2022). The high phytochemical content found in grape seed extract was most likely responsible for increasing the antiradical ability of the grape seed extract-containing yogurt (Tami et al. 2022). Moreover, peanut sprouts yogurt showed higher antioxidant activity (2,2-diphenyl-1-picrylhydrazyl radical: 25.07% and 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid): 24.75) than plain yogurt (2,2-diphenyl-1-picrylhydrazyl: 17.10 and 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid): 17.03). Peanut sprouts have plentiful bioactive

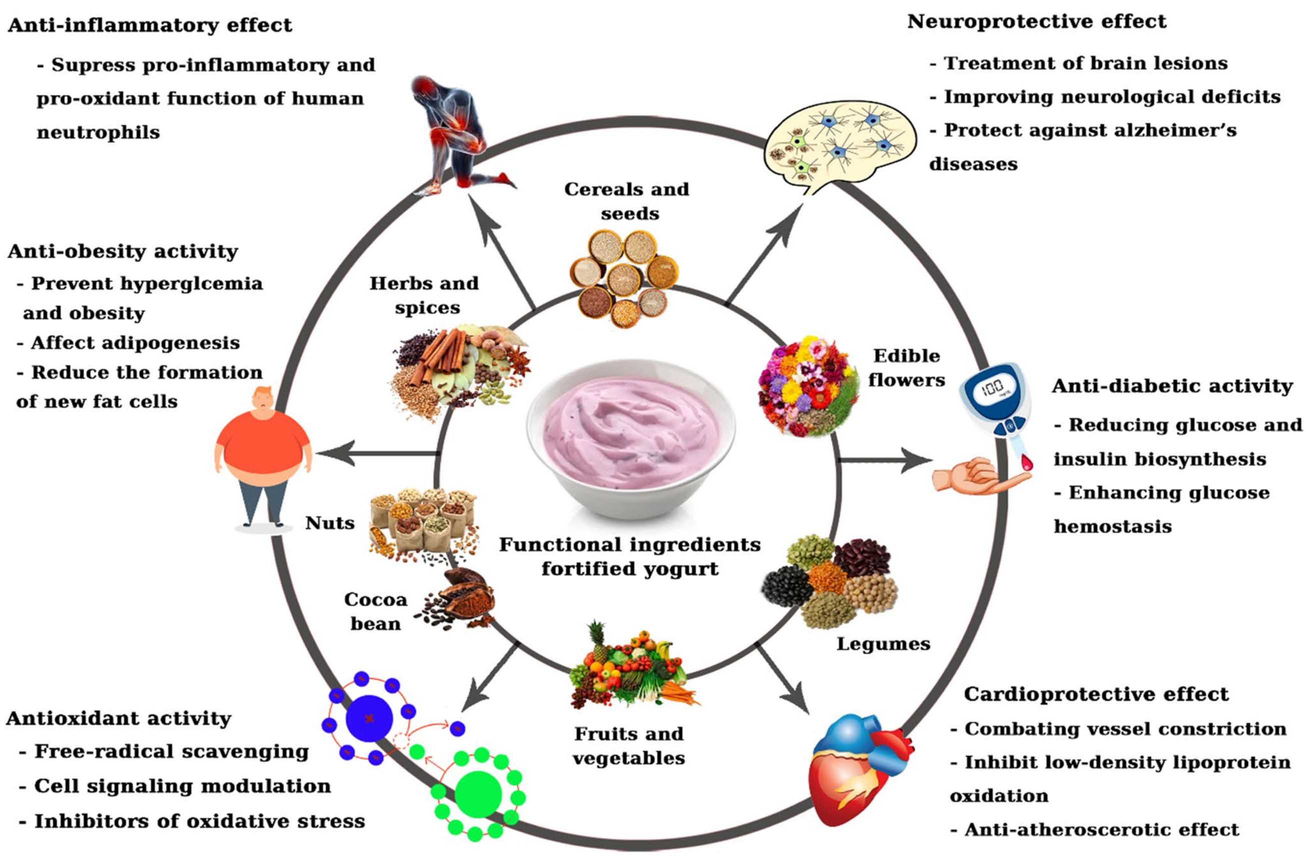

Fig. 5 Biological activities of yogurt enriched with natural food additives. Several natural food additives, such as fruit, vegetable, cereal, edible flowers, and others, can be incorporated into yogurt. The addition of natural food additives improved the antioxidant activity of yogurt. Yogurt fortified with natural food additives has antidiabetic and anti-obesity activities. The anti-inflammatory activity of yogurt significantly increased with adding natural food additives. Consumption of functional yogurt can protect against cardiovascular disease

substances such as resveratrol and other polyphenols, which can show strong antioxidant activity (Yu et al. 2022).

In summary, adding natural functional ingredients to yogurts significantly increased antioxidant activity of yogurts, and this effect is attributed to the high nutritional value of natural functional ingredients such as polyphenols, polysaccharides, amino acids, vitamins, and others. To confirm this explanation, upon increasing the concentration of natural functional ingredients, much more increases in the antioxidant activity of enriched yogurts have occurred.

Antidiabetic and anti-obesity activities

The intake of natural functional ingredients is one of the crucial options for inhibiting the growing of these diseases. Yogurt supplemented by natural functional ingredients is a beneficial way to consume healthy food because of the ability of yogurts to carry various types of natural functional ingredients and increase their consumer acceptability (Basiri et al. 2022; Dong et al. 2022).

In Swiss albino male mice with hypercholesterolemia, oral administration of soy yogurt with rice bran oil-sesame oil for 8 weeks at a dose of 2.5 g/kg body weight significantly decreased blood levels of total cholesterol, low-density lipoprotein cholesterol, and triglycerides, as well as resulted in a significant reduction in the atherogenic index when compared to regular chow diet alone (Sengupta et al. 2016). Furthermore, administration of bio-fortified soy yogurt significantly increased the level of high-density lipoprotein cholesterol in serum, increased the level of superoxide dismutase and catalase in liver homogenate, and significantly decreased the serum activities of alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase, acid phosphatase, and gamma-glutamyl (Sengupta et al. 2016). The effects may be due to the ability of the oryzanol and lignan found in rice bran oil-sesame oil to hasten the decomposition of free radical species generated during cholesterol administration (Sengupta et al. 2016). Animals administered synbiotic yogurt augmented with monk fruit extract (a sweetener) for 42 days showed remarkable modulation of blood glucose as well as a significantly lower level of insulin resistance and glycosylated hemoglobin than rats given yogurt sweetened with sucrose. The state of the gut microbiota and short-chain fatty acid levels was also found to have significantly improved (Ban et al. 2020).

In addition, rats given synbiotic yogurt enriched with monk fruit extract had lessened liver and kidney damage. Additionally, immunohistochemical testing revealed that synbiotic yogurt prevented β-cell loss in comparison with control yogurt and that consuming it helped to regenerate the islets of Langerhans. Mogrosides and the synergistic effects of the prebiotics and probiotics in yogurt may be the main causes of the antidiabetic benefit of synbiotic yogurt enhanced with monk fruit extract (Ban et al. 2020). According to an *in vitro* study, soy milk yogurts have the best inhibition rates for the enzymes α-glucosidase, α-amylase, and dipeptidyl peptidase-4, as well as the strongest inhibitory activity to produce Nω-(carboxymethyl) arginine and Nε-(carboxymethyl) lysine. Additionally, compared to soy milk, soy milk yogurt had larger percentages of aglycone isoflavones and demonstrated a higher level of fluorescent advanced glycation end-product inhibitory action (Nakashima et al. 2022). These effects could be caused by the fact that soy milk yogurt contains a variety of bioactive substances that can deactivate the enzymes that induce diabetes, such as aglycone isoflavones, saponins, peptides, and free amino acids created during fermentation with lactic acid bacteria (Nakashima et al. 2022).

To summarize, oral administration of yogurt enriched with natural food additives significantly decreased blood levels of total cholesterol, low-density lipoprotein cholesterol, and triglycerides, as well as resulted in a significant reduction in the atherogenic index when compared to the regular chow diet alone.

Anti-inflammatory and cardioprotective activities

Probiotic common bean yogurts showed strong anti-inflammatory activity as demonstrated in suppressed tumor necrosis factor α-induced interleukin-8 secretion in Caco-2 and HT-29 cell lines compared to their corresponding milk because of the presence of high contents of individual phenolic and peptide in yogurts, the enhanced activity in yogurt may come from the actions of the probiotic bacteria (Chen et al. 2019a). Inhibitory effects on tumor necrosis factor α-induced interleukin-8 release in Caco-2 and HT-29 cells were shown by the molecular weight fraction of yogurts with a molecular weight < 10 kDa of navy bean and light red kidney bean. The inhibition was, however, significantly stronger in Caco-2 cells compared to HT-29 cells, indicating the involvement of peptide transporters like the human peptide transporter for improving the cellular uptake of the peptides and subsequently increasing anti-inflammatory activity in the Caco-2 cells (Chen et al. 2019a).

Furthermore, *in vivo* study (male albino rats) showed that consumption of stirred yogurt supplemented by *Malva parviflora* leaves extract nanoemulsion significantly protected rats' colons against acetic acid-induced ulcerative colitis. In which rat's pretreatment with stirred yogurt supplemented by *M. parviflora* leaves extract nanoemulsion inhibited the generation of pro-inflammatory cytokines, including tumor necrosis factor-α, interleukin-6, and nuclear factor kappa-B, as well as inhibiting the generation of reactive oxygen species and scavenges free radicals to improve antioxidant defense enzymes against acetic acid-induced ulcerative colitis (El-Naggar et al. 2020). As demonstrated in Caco-2 and HT-29 cell lines, goat milk yogurts fortified with oyster hydrolysate are promising food with anti-inflammatory activity. The digestate fractions with a molecular weight of less than 10 kDa showed high cellular antioxidant activity and anti-inflammatory activity. As evidenced by the inhibition of lipopolysaccharide-induced tumor necrosis factor-α, interleukin-1β, and interleukin-6 production, oyster hydrolysate peptide fractions of molecular weight 10 kDa exhibited cellular anti-inflammatory activity. The 500 g/mL oyster hydrolysate peptide fractions with molecular weight < 10 kDa pretreatment of the Caco-2 and HT-29 cell lines demonstrated the expression suppression of nuclear factor kappa-B p65 protein (Liu et al. 2022). The oyster hydrolysate digestates contained 288 peptides as well as 17 peptides that were expected to be connected to the control of gastrointestinal mucosal activity, which contributed to this activity (Liu et al. 2022).

Because natural functional ingredients include bioactive components that confer this protective effect, consuming yogurts fortified with natural functional ingredients can alter the levels of total cholesterol, low-density lipoprotein cholesterol, triglycerides, and high-density lipoprotein cholesterol. Probiotic-fermented purple sweet potato yogurt containing high γ-aminobutyric acid was studied by (Lin et al. 2012) to see how it would affect the prevention of ventricular hypertrophy in spontaneously hypertensive rat hearts. Compared to the control, they discovered that the spontaneously hypertensive rat's aberrant cardiac architecture and expanded interstitial spaces were dramatically reduced after ingesting probiotic-fermented purple sweet potato yogurt (sterile water group). Furthermore, probiotic-fermented purple sweet potato yogurt treatment reversed the protein levels of the pathways linked to hypertrophy. Consumption of probiotic-fermented purple sweet potato yogurt may suppress the dephosphorylation of the nuclear factor of activated T-cells, cytoplasmic 3, hence inhibiting the activation of atrial natriuretic peptide and B-type natriuretic peptide and ultimately halting the growth of cardiac hypertrophy (Lin et al. 2012).

To summarize, natural functional ingredients include several bioactive components that can protect against inflammation and cardiovascular disease; thus, consuming yogurts fortified with natural functional ingredients can alter the levels of total cholesterol, low-density lipoprotein cholesterol, triglycerides, and high-density lipoprotein cholesterol that can assist the occurring of inflammation and cardiovascular disease.

Antibacterial and anticancer activities

Yogurt enriched with phycocyanin showed a good antibacterial against *Escherichia coli* and *Staphylococcus aureus*, where the presence of phycocyanin in yogurt completely prevented the growth of pathogenic bacteria even during the entire storage period. Stirred-type yogurt supplemented with grape seed extract had a great effect on inhibiting the growth of the tested pathogens such as *E. coli* and *S. aureus*. Besides, this effect significantly increased with increasing the concentration of grape seed extract in yogurt, indicating that grape seed extract contains antibacterial components besides the presence of milk bioactive peptides (Tami et al. 2022). Stirred-type yogurt supplemented by 15% carob molasses showed potent antimicrobial activity against *Bacillus cereus*, *E. coli* and *S. aureus*, *Enterococcus faecalis*, *Shigella* spp., and *Salmonella typhi*, where the inhibition zone diameter (mm) was 22.33, 25.67, 6.02, 29.00, 29.33, 30.67, and 28.33 compared to the control sample that did not show an inhibitory effect on the tested strains, except it showed low antibacterial activity against *E. coli* (7.33) (Shalabi 2022).

For the healthy cell model (BJ-1), stirred-type yogurt containing 0% grape seed extract had the lowest percentage of cell death, while yogurt containing 0.1, 0.25, and 0.5% grape seed extract increased the percentage of cell death insignificantly (Tami et al. 2022). In contrast, the anticancer activity of 0% grape seed extract yogurt against cancerous cells (MCF-7 and HCT-116) was 17.73 and 33.76% cell death, respectively. Furthermore, yogurt containing 0.5% grape seed extract significantly increased cytotoxicity activity, achieving 62.47 and 70.36% cell death against MCF-7 and HCT-116 cancer cell lines, respectively. The phenolic substances found in fortified yogurt derived from grape seed extract played an important role in anticancer activity (Tami et al. 2022).

Furthermore, rice-based yogurt fermented by lactic acid bacteria showed the highest cytotoxicity activity against CaCo-2 colon cancer cells, where IC_{50} ranged between 107.8 and 167.8 µg/mL, while it was not toxic (safe) on normal cell lines where IC_{50} ranged between 445.9 and 537.9 µg/mL (Fawzi et al. 2022). The anticancer activity of rice-based yogurt fermented by lactic acid bacteria could be attributed to the effects of organic acids and exopolysaccharide activities, specifically rEPS (released exopolysaccharides) and cbEPS (cell-bound exopolysaccharides) (Fawzi et al. 2022). MTT-based assays showed that stirred-type yogurt supplemented by 15% carob molasses showed potent cancer activity against HCT116, MCF7, and Hela cell lines where the cytotoxicity (IC_{50}) was 19.07 µg, 10.94 µg, and 23.76 µg, respectively (Shalabi 2022).

To summarize, the presence of natural functional ingredients in yogurt completely prevented the growth of pathogenic bacteria even during the entire storage period. Besides, yogurt containing natural functional ingredients extract significantly increased cytotoxicity activity against MCF-7 and HCT-116 cancer cell lines.

Conclusion

Yogurt consumption can improve the body's ability to absorb minerals and vitamins, as well as increase immunity, assist with weight management, and lower the risk of cancer. However, conventional yogurt lacks several nutrients, including phenolics, flavonoids, anthocyanins, iron, and others, so it has fewer biological effects such as antidiabetic, antiobesity, antibacterial, and anticancer. As a result, enriching yogurt with natural functional ingredients can increase both the physicochemical characteristics of yogurts as well as their biological activity. This is because natural functional ingredients can offer a variety of nutrients, including polysaccharides, phenolics, flavonoids, anthocyanins, and amino acids. They can also act as a natural stabilizer and texturizing agent, as well as enhance the microstructure, color, texture, and other qualities of yogurt. The addition of natural functional ingredients to yogurt greatly improved its apparent viscosity, texture, sensory qualities, microstructure, and chemical composition, as well as the water-holding capacity and number of viable cells of lactic acid bacteria. It also decreased syneresis and fat globule loss. Additionally, adding natural functional ingredients significantly improved the biological effects of yogurt, including its antioxidant, antidiabetic, anti-inflammatory, antibacterial, and anticancer properties. However, extensive clinical trials or studies *in vivo* on the human system are required to determine the long-term treatment effects of functional yogurts and the half-life period and optimum dosage for beneficial effects.

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Declarations

Conflict of interest The authors declare that there are no conflicts of interest.

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