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Nutritional and therapeutic benefits of coconut milk and its potential as a plant-based functional yogurt alternative: a review

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ABSTRACT

Plant-based milks are on the rise due to an increased awareness of their sustainability and health benefits. Currently, dairy milk is the most nutritionally complete beverage, but it suffers from the presence of indigestible lactose and allergenic proteins. Coconut milk has been around for a long time, but its application is limited due to a perceived lack of specific nutrients, high saturated fat levels, and low acceptability. Recent evidence indicates, however, that the saturated fat and other plant-based components found in coconut milk are good for metabolic outcomes and brain health. The conversion of coconut milk to yoghurt will further improve its functionality by boosting its existing nutritional qualities. In this article, the nutritional value of coconut milk, as well as its potential downsides, its application as yoghurt, and suggestions for enhancing its nutritional functionality will be examined.

1. Introduction

As the global human population increases, there is a tremendous strain on food production to feed everyone[1]. In recent years, plant-based milk (PBM), such as soy, almond, oat, and coconut milk (CM), has gained popularity as an alternative to conventional dairy milk[2]. They are more sustainable as their growth involves fewer ethical, resource, and deforestation concerns[3]. PBM is still burdened by the greater costs associated with the industry's infancy, including research and development, packaging, overhead, and marketing, among others[4]. However, according to a recent study by Khanal and Lopez[5], environmentally conscientious buyers are willing to pay more for PBM. As there is little price relationship ("price elasticity") between dairy and PBM, providing extra incentives and encouraging wider adoption will reduce the cost in the long term[4].

CM is typically characterised as a protein-oil-water aqueous solution derived from mature coconut endosperm, with or without potable water. As the husk and shell of the coconut grow, the embryo sac's cavity enlarges significantly and subsequently fills with fluid. After a few months of growth, the husk and shell of this fruit will become thicker. Then, the firm endosperm will form against the inner wall of the hollow, followed by the production of the soft, white endocarp, which will harden and turn a dark brown hue. Typically, the coconut fruit matures within a year of its development[6]. In addition to the skin colour, the selection of mature coconuts can be decided by the number of bunches[7-8]. As most mature coconuts are collected

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from a coconut tree which can grow up to 30 m tall, followed by a lengthy de-husking procedure, coconut extraction is typically a labor-intensive endeavour[9].

One of the earliest and most comprehensive reviews on the nutritional properties of CM, in general, is by Seow and Gwee[10]. Based on quantities of coconut oil, non-fat solids, and water, the authors of this review classified CM into 5 subtypes: 1) concentrated; 2) undiluted; 3) cream; 4) milk; and 5) light. Typically, CM must have greater than 30% fat and 3% proteins, along with 55% water; this figure can increase if the CM is concentrated by standing or centrifuging. Before extraction, the CM can be pasteurised, or the mature flesh can be blanched, depending on the method, to increase its shelf life[10]. The high saturated fat content of CM (and its derivatives) is comparable to that of butter, palm oils, and animal fats; hence it is commonly considered unhealthy. Recent information, however, indicates that CM or its oil is not as harmful as originally believed[11].

By definition, yoghurt may be manufactured from nearly any type of milk with appropriate protein and sugar content. Although cow's milk is the preferred substrate due to its history, cultural acceptance, and milder flavour, dairy yoghurts have significant limitations or disadvantages. Although yoghurt may be less allergic than dairy milk, allergens such as casein and whey protein may still be present in small amounts[12]. Lactose intolerance also poses a problem to specific populations[13]. In addition, many manufacturers add additional sugars and flavourings to boost the fermentation efficiency and consumer acceptance of yoghurt[14]. Consequently, traditional types of dairy-based yoghurt may contain indigestible lactose and allergenic proteins, and also be high in sugar and additives.

An alternative to dairy-based yoghurt is PBM yoghurt, which can be processed in a way that offers probiotic advantages. Since the sugar content (glucose) of PBM differs from that of dairy (lactose), other lactic acid bacteria (LAB), such as *Lactobacillus casei*, *L. rhamnasus*, and *Bifidobacterium bifidum* may be required[15]. Through probiotics in the form of LAB, the conversion of CM to yoghurt may improve its functionality. For example, probiotics may reduce the sugar level or raise certain bioactive components' concentration in CM, enhancing its health benefits. In this review, the features of CM, especially from a nutritional standpoint, and its conversion into yoghurt will be examined. Therefore, future directions and potential enhancements for this product will be recommended.

2. Nutritional and health properties of CM

2.1 Carbohydrates and proteins

In the early 1980s, abundant evidence suggested that the increase in cardiovascular disease (CVD) related diseases were due to saturated fat consumption. However, contemporary research is indicating that each nutrient, especially without human intervention, is indispensable in its own way. Currently, due to the increase in processing capacities of food industries, numerous natural foods have been "refined" and stripped of their nutrients to concentrate on a particular nutrient. The paradigm of nutrition has begun to shift toward a healthier moderated consumption of each nutrient, rather than the amount itself[16].

Sugar content is generally low in coconut, including its flesh and water. The mature flesh of coconut contains less than 8.3% carbohydrates and is primarily comprised of sucrose and starch[10]. Based on Table 1, the sugar content of CM is approximately 3%, which is comparable to that of dairy milk. Currently, no literature indicates how the carbohydrate content of mature coconut flesh changes. However, the composition of sugars between dairy and CM is distinct, as CM contains sucrose rather than lactose[17-18]. This property can benefit an individual with lactose intolerance, which accounts for more than half of the world population[13]. The trouble digesting lactose tends to manifest in people of colour, such as Asian descent[19]. Therefore, coconut-based ingredients are highly

Table 1
Nutritional composition of coconut, dairy, soy, and almonds and the daily reference value in the United States.

Nutrients	Units	CM (FDC: 170173)[a]	DM (FDC: 171266)[b]	SM (FDC: 2257044)[c]	AM (FDC: 2257045)[d]	DRV[e]
Water	g	72.9	87.7	91.5	96.5	N/A
Energy	kcal	197	64	41	19	2 000
Protein	g	2.02	3.28	2.78	0.66	50
Total lipid (Fat)	g	21.3	3.66	1.96	1.56	78
Ash	g	0.97	0.72	0.75	0.6	N/A
Carbohydrate	g	2.81	4.65	3	0.67	275
Ca	mg	18	119	155	158	1 300
Fe	mg	3.3	0.05	0.37	0.12	18
Mg	mg	46	13	17.5	8.2	420
P	mg	96	93	46	19	1 250
K	mg	220	151	118	49	4 700
Na	mg	13	49	39	59	2 300
Zn	mg	0.56	0.38	0.26	0.08	11
Cu	mg	0.223	0.01	0.096	0.027	0.9
Mn	mg	0.768	0.004	0.16	0.056	2.3
Vitamin C	mg	1	1.5	N/A	N/A	90
Vitamin B_1	mg	0.022	0.038	0.044	0.005	1.2
Vitamin B_2	mg	0	0.161	0.331	0.083	1.3
Vitamin B_3	mg	0.637	0.084	0.133	0.089	16
Vitamin B_5	mg	0.153	0.313	N/A	N/A	5
Vitamin B_6	mg	0.028	0.042	N/A	< 0.01	1.7

Table 1 (*Continued*)

Nutrients	Units	CM (FDC: 170173)[a]	DM (FDC: 171266)[b]	SM (FDC: 2257044)[c]	AM (FDC: 2257045)[d]	DRV[e]
Vitamin B_9	μg	14	5	16	< 6	400
Vitamin B_{12}	μg	0	0.36	1.33	0.45	2.4
Vitamin A	μg	0	33	89	61	900
VD_2 + VD_3, Vitamin D	μg	0	N/A	4.63	1.59	20
SFA	g	18.9	2.28	N/A	N/A	20
SFA 6:0	g	0.121	0.07	N/A	N/A	N/A
SFA 8:0	g	1.49	0.041	N/A	N/A	N/A
SFA 10:0	g	1.19	0.092	N/A	N/A	N/A
SFA 12:0	g	9.46	0.103	N/A	N/A	N/A
SFA 14:0	g	3.74	0.368	N/A	N/A	N/A
SFA 16:0	g	1.81	0.963	N/A	N/A	N/A
SFA 18:0	g	1.1	0.444	N/A	N/A	N/A
MUFA	g	0.907	1.06	N/A	N/A	N/A
MUFA 18:1	g	0.907	0.921	N/A	N/A	N/A
PUFA	g	0.233	0.136	N/A	N/A	N/A
PUFA 18:2	g	0.233	0.083	N/A	N/A	N/A
Cholesterol	g	0	14	N/A	N/A	300
Tryptophan	g	0.024	0.046	0.034	0.001	N/A
Threonine	g	0.074	0.148	0.1	0.01	N/A
Isoleucine	g	0.079	0.198	0.1	0.026	N/A
Leucine	g	0.15	0.321	0.2	0.046	N/A
Lysine	g	0.089	0.26	0.2	0.031	N/A
Methionine	g	0.038	0.082	0.033	0.001	N/A
Cysteine	g	0.04	0.03	0.049	0.001	N/A
Phenylalanine	g	0.102	0.158	0.157	0.042	N/A
Tyrosine	g	0.062	0.158	0.1	0.019	N/A
Valine	g	0.122	0.22	0.101	0.018	N/A
Arginine	g	0.331	0.119	0.2	0.092	N/A
Histidine	g	0.046	0.089	0.1	0.014	N/A
Alanine	g	0.103	0.113	0.1	0.029	N/A
Aspartic acid	g	0.197	0.249	0.329	0.078	N/A
Glutamic acid	g	0.462	0.687	0.486	0.138	N/A
Glycine	g	0.096	0.069	0.1	0.045	N/A
Proline	g	0.083	0.318	0.114	0.031	N/A
Serine	g	0.104	0.178	0.171	0.02	N/A

Note: The milk's statistics were retrieved from the USDA FoodData Central Database (FDC)[115]. [a]CM: CM, canned milk (liquid expressed from grated meat and water), published 4/1/2019. [b]DM: Dairy milk, producer, fluid, 3.7% milkfat, published 4/1/2019. [c]SM: Soy milk, unsweetened, plain, refrigerated, published 28/4/2022. [d]AM: Almond milk, unsweetened, plain, refrigerated, published 28/4/2022. [e]DRV: US daily reference value for > 4 years old[122]. N/A: not available; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

desirable, at least from a "low sugar" and "lactose-free" standpoint. Coincidently, the coconut is primarily grown in those areas, providing an alternative solution to the population that does not consume dairy.

Coconut flesh and milk are also rich in soluble and non-soluble fibres[20-21]. Both fibre types are indigestible by the human digestive system. However, once they reach the upper small intestine, they serve distinct functions. In the case of soluble fibre, this fibre will serve as a substrate for the growth of gut bacteria ("probiotics"), hence the term "prebiotics." As the bacteria internalise the substrates, numerous clinically significant metabolites ("postbiotics"), including short-chain fatty acids, amino acids, vitamins, and other bioactive compounds, are produced. As for insoluble fibre, this substance will make up most of the human waste, eliminating toxins and promoting bowel movement. These coconut-based ingredients are also rich in prebiotics oligosaccharides, which are essentially short-chain sugars that the body cannot digest due to specific glycosidic bonds[22].

PBM typically contains fewer amino acids than dairy alternatives. Soy milk (or legume-based) is likely the best PBM for amino acids in terms of amino acid composition and other nutritional components (Table 1). However, compared to other nut-based milk, CM contains a respectable amount of amino acids with an optimal proportion of amino acids. It has been demonstrated that the proportion of essential amino acids in CM is among the highest in alternative milk products, exceeding 70%[6-17]. For example, the amount of all essential amino acids in almond milk is significantly lower than in CM although not as complete as dairy milk (Table 1).

Similar observations can also be made regarding the non-essential amino acids, but this topic will not be further explored as the human body is capable of synthesising them *de novo*. Interestingly, CM also contains the highest levels of γ-aminobutyric acid (GABA), an important non-proteinogenic amino acid (NPAA) mainly produced in food related to plants and microorganisms[17,23-24]. Supplementation of natural GABA in food products is desirable due to its low side effects while conferring biological actions such as regulating cardiovascular processes, easing neurological symptoms, improving liver and kidney functions, and protecting against alcohol-induced disorders[25]. In fact, as the research is still ongoing, more NPAA in CM might be present based on the theoretical biosynthetic pathways of plant metabolism. These components include ornithine, citrulline, arginosuccinate, homoserine, homocysteine, cystathionine, and β-amino acids which are well-known to be present in most plant species. For example, pipecolic acids are thought to be present in all plants as signalling molecules for plant development, physiology, and defense[26]. These bioactive compounds, similar to GABA, can confer multiple health benefits to humans[27].

2.2 Fat

Compared to dairy and other PBM, the most intriguing aspect of CM is its high saturated fat content. The total fat content in soy or almond milk can be high, but the percentage of saturated fat is lower[28]. In contrast, CM contains up to 90% saturated fat[29], resulting in significant calorie values. As a result, a high consumption of CM is not recommended, as many dietary guidelines advise a lower saturated fat intake[30]. These recommendations are based on a few epidemiological studies demonstrating the increased coronary risk associated with high saturated fat diets. However, the studies did not identify the specific fatty acids that contributed to these effects; rather, they were conducted on a broad scale. Subsequent studies have emphasised the importance of specific fatty acids for positive cardiometabolic outcomes, provided they are consumed within the recommended intake range[31].

Walther et al.[17] found that among 27 Swiss dairies and PBM–cashew, almond, and soy milk had the highest fat content, whereas CM, oat, and rice milk contained an average amount of fat. All other PBM contains long-chain unsaturated fatty acids, except the one that is fortified with coconut fat. Polyunsaturated fats are clinically important as they include essential fatty acids (EFA) that cannot be synthesized *de novo* by the body. Omega-6 and omega-3 EFAs play crucial roles in various metabolic processes, but an imbalanced consumption, particularly an excessive intake of omega-6, can have adverse effects on metabolic health. The ratio of omega-6 (pro-inflammatory) to omega-3 (anti-inflammatory) fatty acids in the CM-based beverage is 11:1−18:1, which is second only to soy-based beverages (7:1−8:1). In contrast, almond and rice-based milk contain up to omega-6:omega-3 ratio of 235:1 and 175:1, respectively[17]. The consumption of a higher ratio of omega-3 to omega-6 is highly important to guard against inflammatory-induced conditions in humans, such as CVD-, cancer-, autoimmune- and neurological-based disorders[32].

"The dose makes it a poison" is a timeless adage by the father of toxicology–*Paracelsus*. Like any substance, CM is safe to consume if it stays within the set limits. Furthermore, it was demonstrated that the majority of fatty acids in CM (more than 70%) are medium chain saturated fatty acids (MCTs, also known as MCFAs), which are about C_6–C_{12} in length[17,33-34]. While MCTs are not classified as EFA, they offer unique metabolic benefits. Unlike long-chain fatty acids (> 14 C), MCTs are absorbed differently. MCTs are favoured more as an energy fuel than as fat because they can enter directly into portal veins rather than be absorbed through the typical fat metabolic pathway (Fig. 1). In typical fat absorption, the largest lipoprotein, called chylomicrons, is formed by long-chain fatty acids and cholesterol-derived substances when they enter lymphatic systems. Chylomicrons are then transported to the liver, destined to combine with extra acetyl-CoA produced from sugar to form lipoproteins, including very low-density lipoprotein (VLDL), intermediate-density lipoprotein (IDL), and low-density lipoprotein (LDL). LDL is referred to as bad cholesterol, as they tend to build up in blood vessels and cause obstruction, especially when it is dense and has atherogenic qualities[35].

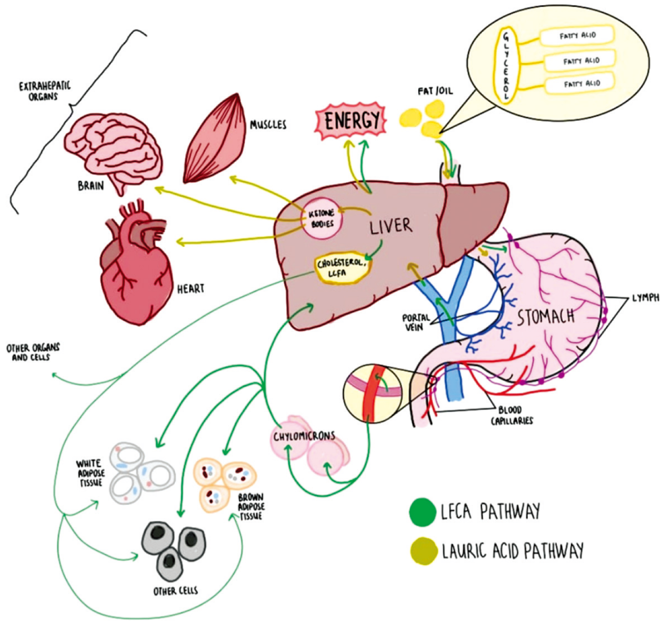

Fig. 1 Normal fat metabolism involves the formation of chylomicrons in lacteal, the lymphatic vessel before the cholesterol enters the bloodstream. Some MCTs are absorbed differently, which results in various fates and uses. MCTs, which make up a significant percentage of coconut-based goods, may improve metabolic outcomes by raising high-density lipoprotein cholesterol (HDL-C) and lowering low-density lipoprotein cholesterol (LDL-C).

MCTs, abundant in coconut-based goods, may improve metabolic outcomes by lowering LDL levels and raising HDL levels[33,36-38]. Recent studies have shown that consuming CM proteins and oils in middle-aged to elderly rats increases the expression of endothelial nitric oxide synthase (eNOS) and cystathionine γ-lyase (CSE). This leads to increased production of NO and H_2S from blood vessels, resulting in reduced vasocontraction to phenylephrine and improved relaxation to acetylcholine. These findings suggest positive effects on cardiovascular markers[39-41]. It is important to note that these processes take place when the fat intake is wholesome (i.e., not refined into specific components) and under appropriate circumstances (i.e. not in the state of overfed)[34]. This situation is similar to white sugar, whereby excessive processing in manufacturing leads to unhealthy foods which are otherwise healthy if taken in their original form.

Furthermore, because the carbon is shorter than 14 C, the MCTs can enter mitochondria without the carnitine transporter, accelerating the pace at which they are used as energy during aerobic metabolism (Fig. 2). Instead of producing glucose during fasting, the liver produces ketone bodies by beta-oxidizing fat. This state is similar to fasting, which is beneficial to the body. Ketone bodies can traverse the blood-brain barrier to fuel the brain, providing therapeutic advantages for various brain-related disorders, including epilepsy, stroke, Parkinson's disease, Alzheimer's disease, and many others[42-43]. Ketones are much more effective energy sources that improve neuron bioenergetics and cognitive performance and prevent neurodegeneration by reversing amyloid-β aggregation[44]. They also control key signalling processes, such as regulating brain-derived neurotrophic factor, which stimulates hippocampal neurons and increases their resistance to damage and disease[45-46]. The use of lauric acid (C_{12} fatty acids, a major component of CM) was also demonstrated to stimulate ketogenesis directly in the astrocytes cell line, therefore contributing to overall brain health, including language, executive functions, global cognition, memory and attention (Fig. 3)[47].

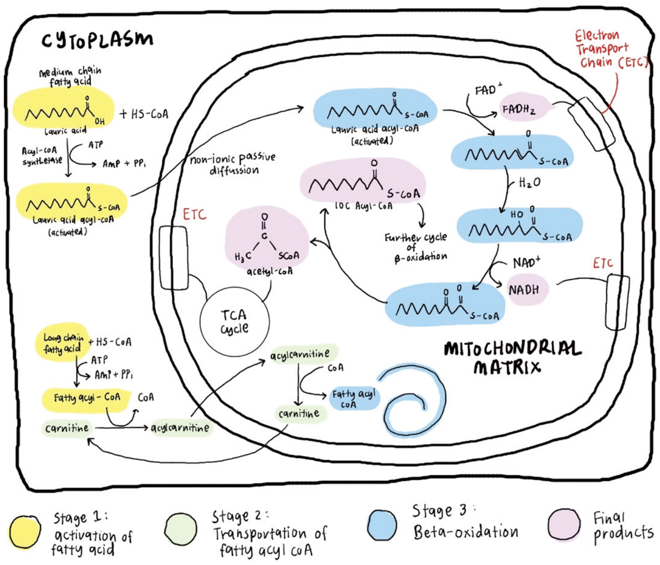

Fig. 2 The beta-oxidation of fatty acids in mitochondria. Fatty acids can be an excellent energy source for metabolically active cells since extra co-enzymes nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide ($FADH_2$) are generated during the spiral reaction. It should be noted that a specific carnitine transporter is necessary to pass the mitochondrial membrane. However, in some situations (such as with medium- to short-fatty acids), this procedure can be bypassed, dramatically speeding up the rate at which fatty acids are used as fuel.

Consuming healthy fats like MCTs (and proteins), especially those from plant sources, can lower blood sugar levels, prevent diabetes, enhance insulin sensitivity, boost satiety, and train the body to use fat as a source of energy instead of glucose[48]. Supplementing with coconut fat improved lipid profiles, lowered lipid peroxidation indicators, and improve liver antioxidative and anti-inflammatory activities in *in vivo* studies[49-51]. Similarly, Hauy et al.[52] found that rats fed high protein diets and CM reduced visceral fats and body weight. In addition, lauric acid is known to cause endometrial and breast cancer cells to undergo apoptosis, which strengthens the immune system[53].

Although there is little research on myristic acid (C_{14}), this saturated fatty acid, like lauric acid, is likewise, interesting. This molecule is abundant in dairy milk and CM, as seen in Table 1. Earlier studies have linked this chemical to typical cardiovascular disorders, fat build-up, and LDL-C rise[54]. However, a recent research indicates that myristic acid is essential for a variety of biological activities, including post-translational protein modification, modulation of the immune system, and improvement of long-chain omega-3 fatty acid levels and HDL-C composition in the blood plasma[55]. Furthermore, a few more studies concluded that myristic acids have low contributions toward CVD-related causes[31].

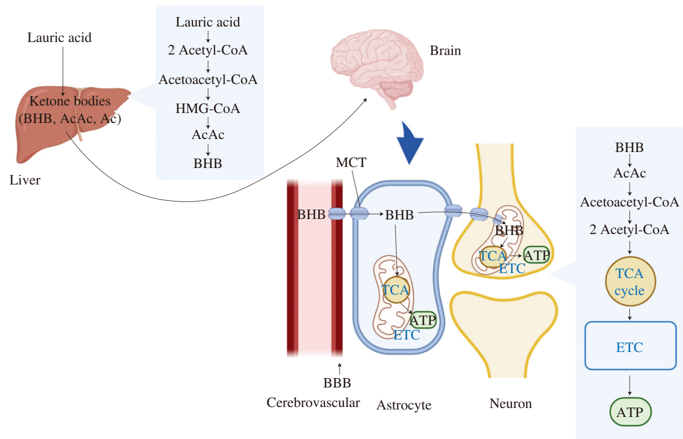

Fig. 3 Supplementation of energy in form of ketone bodies (acetoacetate (AcAc), acetone (Ac), and β-hydroxybutyrate (BHB)) during neurodegenerative diseases. BHB in cerebrovascular can pass through the blood-brain barrier (BBB) and enters the astrocytes and neurons by passing through monocarboxylate transporters. BHB goes into mitochondria, and it is changed into in the order of AcAc, acetoacetyl-CoA, and acetyl-CoA for ATP generation via the tricarboxylic acid (TCA) cycle and electron transport chain (ETC).

2.3 Micro- and non-nutrients

CM is equivalent to or exceeds dairy and other PBM in vitamin content (Table 1). Besides specific vitamins such as vitamins A and D, CM is rich in vitamin B, an essential group of co-enzymes for energy metabolism. As CM is rich in fat, it can also aid in the absorption of fat-soluble vitamins that are not present in CM, such as vitamins A, D, E, and K. Another advantage of CM is that it contains more minerals than dairy and PBM, except for the essential mineral calcium (Ca). For example, Mg, Fe, Cu, and Mn are at least three times more abundant than in other milk (with some at least 10 folds higher). The low sodium content in CM is beneficial as excessive sodium consumption, which is common in many other food sources, can lead to hypertension.

The mineral composition of CM varies due to its bioaccumulation from the soil and the maturation process of coconuts. Unfortified CM has been found to contain significant levels of P, Mg, and Zn, with studies by Tulashie et al.[9] and Rincon et al.[56] supporting these findings. While CM falls slightly short in terms of Ca content and bioavailability compared to dairy milk[57], it is noteworthy for its superior levels of other minerals. The need for higher mineral levels during coconut tree maturation, especially for germination and root development, contributes to the differences in mineral content[8]. This is further supported by the presence of substantial amounts of minerals (such as K, Mg, Ca, P, Mn, Cu, Fe, and Zn) in the coconut haustorium. The haustorium serves as the main source of nutrients for the coconut flesh (which is used to produce CM) and coconut water during the sprouting process[58]. It's important to note that mineral content in PBM alternatives may vary depending on additional processing methods[59].

As a PBM, CM can benefit from the presence of plant-based chemicals, such as phytosterol, or plant cholesterol (mainly beta-sitosterol)[28]. The level of beta-sitosterol was discovered to be as high as 191 mg/L, which is greater than the 175 mg/mL reported in almond milk. Phytosterol is a plant bioactive molecule that has been linked to anti-cancer, immunomodulation, cardiovascular health, and collagen synthesis, while not being a nutrient (because it is not necessary for essential living processes)[60-61]. A recent review argued that phytosterols can cross blood-brain barriers and confers their impact directly, especially on the ageing brain[62]. Consequently, it is believed that this compound's anti-inflammatory effects, regulation of nitric oxide, cytokines, cyclooxygenase-2, and phosphorylated protein kinase, and regulation of nitric oxide, cytokines, and cyclooxygenase-2, can enhance numerous central nervous system (CNS)-related disorders[63].

Moreover, the phenolic compounds in CM-based drinks were reported to be among the highest in PBM (almond, soybean, rice, and oat), at around 7 mg GAE/L[64]. A recent finding by Karunasiri et al.[65] found the significant phenolics in CM are gallic, chlorogenic, parahydroxybenzoic, caffeic, vanillic, syringic, and ferulic acid. These compounds are beneficial for human health and in the management of CVD[66]. In PBM, the major components of plant-based phenolics, such as isoflavone, flavonoids, and other phenolic compounds, contribute to health, including to the gut[67], brain[68] and cell signalling pathways[69]. Moreover, polyphenols and certain hormones (such as cytokinins) in CM have been suggested as a supplement for several oxidative-mediated neurodegenerative illnesses by supporting the endogenous antioxidant systems, reducing amyloid-β plaques, and neurotrophic factor-mediated cell survival systems[44,70].

3. Possible adverse effects of CM

Not all calories are equal. Due to their varied metabolic fates, the same calorie from glucose is not equivalent to fructose or lactose. In the scientific literature, a glycemic index (GI) score of 70 or more is considered high, whereas a score of 55 or less is considered moderate[71]. However, glycemic load (GL) might be a more accurate indicator as it is based on serving size[71]. Glucose stimulates insulin production the highest, as indicated by its high GI. A high glucose intake (or sucrose) is frequently associated with metabolic disorders.

To those who can tolerate lactose, this simple sugar is likely the healthiest type as it contains an average GI (around 40) while helping absorb certain minerals[72]. Fructose has the lowest GI value (around 20). However, fructose needs to be metabolised in the liver before entering the bloodstream, thus, it is typically turned into fat. Therefore, it has been linked to CVD, particularly in its processed form (e.g., high fructose corn syrup). It may also stimulate the appetite by inhibiting ghrelin (appetite-regulating hormone)[73]. In CM, lactose is absent, but glucose levels are elevated. It is represented by its high GI, which is greater than 90, compared to beverages made

Fig. 4 Common Malay dishes rich in CM. (A) *Nasi lemak* (CM rice); (B) *Nasi dagang* (CM rice with herbs); (C) *Lemang* and *rendang* (glutinous rice with CM and stewed CM beef); (D) *Pengat* (warm CM soup); (E) *Nasi kandar* (mixed rice with CM curries); (F) *Kuih* (Malay dessert with CM as the base); (G) *Dodol* (sweet toffee-like confection with (CM); (H) *Cendol* (sweet CM green jellies iced dessert).

Table 2
Example of the Malay foods that utilise a high amount of CM as the main ingredient[123].

Food	Description	Energy (kcal/100 g)
Nasi lemak	Coconut rice, cooked with CM instead of water	169
Rendang	Braised beef/chicken with CM	253
Dodol	A viscous confection with CM	322
Kuih	Malay dessert (with CM as the base)	~137–238
Nasi dagang	Rice steamed with CM	203
Kari ayam	Malaysian chicken curry, typically cooked with CM	203
Bubur kacang	Mung bean porridge cooked with CM	106
Pengat Pisang/Keledek	Bananas/sweet potato dessert in sweetened CM	140–335

from nuts and legumes, which are usually below 50. However, the GL of CM is equivalent to other PBM (about 4) and far lower than rice-based beverages (around 20)[71].

Due to its particular flavour, CM is frequently used in Asian cuisine. However, overusing CM might lead to obesity and an increase in CVD. In addition, these meals are frequently paired with high-carbohydrate foods, such as Malay sweets. Malaysian cuisine is an excellent illustration of the excessive usage of CM (Table 2). *Kuih*, a category of sugary Malay delicacies, relies largely on CM as its base. Similarly, *Nasi lemak* (CM rice) is a popular breakfast dish with high-calorie content in Singapore, Malaysia, and Indonesia (Fig. 4). Intriguingly, a recent study revealed the potential advantage of combining fat (CM) with rice, which could produce resistant starch[74-75]. This contributes to a reduction in calories and soluble fibre. In addition, as it is eaten with chilli paste, anchovies, eggs, cucumber, and peanuts, the combination can result in a more nutritious end.

CM may have less protein than dairy and similar PBM. However, this is dependent on the coconut's production process and origin. For example, Aydar et al.[28] reported that CM has a moderate to high amount of proteins. However, Jeske et al.[71] and Walther et al.[17] indicated that CM-based products are often low in protein compared to PBM and dairy products with a low protein digestibility score. CM is also deficient in methionine, isoleucine, threonine, and tryptophan, which are the four essential amino acids[6]. Additionally, the most important mineral, i.e., Ca, is low[9]. Therefore, fortification is required if the CM-containing product is intended to replace dairy consumption. Again, the source of CM can have a significant effect, as recent research utilising a sensitive inductively coupled plasma optical emission spectroscopy (ICP-OES) revealed a large amount of Ca (at least 2-fold more than soy and almond milk) can be present in CM[76].

Comparable to other nut-based proteins, CM may include allergens but in low quantities. For example, CM can contain a variety of protein fractions that may lead to allergic reactions (Table 3). Immunoglobulin-E (IgE) cross-reactivity has been documented between coconut and other nuts, particularly almond and macadamia. Based on clinical research involving ten individuals, the Vicilin protein family containing the Coc n 1 allergen has been identified as the primary allergen in coconut[77]. In another study, Iddagoda et al.[78] identified up to 12 and nine allergens in fresh and boiled CM, respectively. The allergenicity of the CM seems to be higher in the patient experiencing anaphylaxis due to higher overall IgE reactivity.

In its simplest sense, nutrients are the substances the body needs to accomplish specific functions. However, some plants produce "antinutrients," a substance that can bind to and inhibit the absorption or digestion of nutrients. This system is believed to have evolved as a defence against predators[79]. Trypsin inhibitors in soy-based products are a prime example of an antinutrient that inhibits protein digestion. PBM can also contain antinutrients such as polyphenols, phytates (which bind to minerals like Ca), tannins (which hinder protein digestion), enzyme inhibitors, lectins (which bind to carbs), and oxalates (which bind to minerals like Ca)[28]. Apart from influencing digestion and absorption, these compounds may also contribute to adverse health effects, such as bloating, kidney stones, decreased bone health, and inflammation[79]. As a nut-based product, CM can possess certain antinutrients, such as phytates[80]. However, the antinutrients in the coconut-based product are generally very low to non-existent[29].

Similar to dairy milk, PBM may contain toxins that have accumulated in the soil or as a result of pesticide use. In their investigation of different Turkey-based PBM, Karasakal et al.[76] discovered that CM includes trace amounts of Sb (0.26–0.42 ppm) and Sn (12–30.4 ppm), which is comparable to soy and almond milk. Furthermore, higher-than-average amounts of Cs and Pb were also detected in the coconut-based product using high resolution continuum source graphite furnace atomic absorption spectroscopy (HR-CS GF AAS) in Brazil[81]. In contrast, Warsakoon[82] found that CM demonstrated the lowest accumulation of heavy metals compared to other parts of coconut using AAS in Sri Lanka. These findings indicated geographical area or method of production plays a major role in the accumulation of toxins in CM.

Table 3
Percentage of proteins fraction of defatted CM.

Proteins	Percentage (%)	Descriptions	References
Albumin	20.90 ± 1.51	Belongs to the prolamin superfamily. Rich in sulfur amino acids. A possible allergen	[77]
Globulin	40.73 ± 4.15	Seed storage protein from the Cupin superfamily. Important for the transport and metabolism of nutrients. The most likely allergen in CM is due to the presence of cocosin and vicilin	[77-78,124-125]
Prolamin	2.43 ± 0.61	Plant storage protein rich in proline and glutamine. Able to form strong, insoluble structures, hence being used to thicken and stabilize food products. Possible allergen, as it is related to gluten	[77]
Glutelin-1	12.17 ± 1.65	Newly classified as part of prolamins. Rich in hydrophobic amino acids. Also, a part of the gluten structure	[6]

Note: The percentage values are derived from [6].

4. An introduction to traditional yoghurt

According to Singh et al.[83], yoghurt is a fermented dairy product obtained from the fermentation of lactic acid bacteria such as *Streptococcus thermophilus* and *L. delbrueckii* subsp. *bulgaricus*. Other lactic acid bacteria (e.g., *L. acidophilus*) or *Bifidobacteria* (e.g., *B. lactis*) are occasionally added. The primary function of *S. thermophilus* in the production of yoghurt is rapid acidification associated with the production of lactic acid. Furthermore, it also produces secondary fermentation products like formate, acetaldehyde, or diacetyl that contribute to the fermented products' aromatic, functional, nutritional, and textural qualities.

At the beginning of fermentation, *S. thermophilus* consumes sugars and multiplies quickly, generating pyruvic acid, formic acid, and carbon dioxide. In turn, these processes help *L. bulgaricus* to grow, while breaking down milk proteins into peptides and amino acids. As a result, these processes encourage *S. thermophilus* development, creating a symbiotic relationship. *L. delbrueckii* subsp. *bulgaricus* is a gram-positive, rod-shaped, and found in chains of variable lengths, most frequently consisting of 3–4 cells. Similar to *S. thermophilus*, the primary product of *L. delbrueckii* subsp. *bulgaricus* is lactic acid, and secondary compounds like acetaldehyde, acetone, acetoin, and diacetyl can also be formed in very small amounts[84]. Due to its distinctive bioactive components and the presence of a live and active culture, LAB also offers extra health advantages beyond nutrient requirements[85]. Numerous studies show that probiotics used in yoghurt have strong antipathogenic and anti-inflammatory properties[86].

As milk is the primary component of yoghurt, many of its benefits are derived from the nutritious qualities of milk. Numerous macro- and micronutrients, amino acids, and health-promoting metabolites, such as antioxidants, are abundant in milk[87]. As a result of the yoghurt's use of probiotics during fermentation, these advantages are augmented, and unfavourable qualities are mitigated. For example, lactose-intolerant individuals are encouraged to consume yoghurt since most milk sugars are degraded by LAB. Similarly, several actions of LAB can lower the allergenicity of milk by releasing proteases that can cleave allergenic proteins and create bioactive peptides that are potentially beneficial to health. Moreover, if the LAB survive the harsh environment of the digestive system, they can colonise and regulate the gut's health, which, according to the notion of a human brain-gut axis, is the hub of human health[86,88-89].

5. The application of CM as a base for alternative plant-based like yoghurt

According to Grasso et al.[90], plant-based yoghurt-like products are typically produced by fermenting aqueous extracts of various raw materials, such as legumes, oil seeds, cereals, or pseudocereals, which have a similar consistency and appearance to cow's milk due to homogenization and breakdown. However, replacing dairy with PBM brings new obstacles from nutritional and acceptance standpoints.

A few authors have reported that commercial plant-based yoghurts such as soy and CM-based yoghurt (CMBY) were identical to dairy yoghurt in terms of sensory acceptability and texture[90-92]. As CM is rich in volatile compounds in the form of fatty acids, the yoghurt can contain a strong "coconutty" taste which can deter consumers that are used to dairy yoghurt[93]. Many researchers opted to add flavourings to improve the sensory properties of CMBY. For example, Mauro et al.[94] used strawberry pulp to increase the taste, while Amirah et al.[92] added raisin puree to significantly improved the texture, nutrients, aroma, taste, and overall acceptability.

When these plant-based systems are acidified, the proteins become destabilised and create a weak, discontinuous gel, which causes the serum to separate, in a process known as "syneresis"[95]. Stabilizers or hydrocolloids are frequently added to CMBY to increase viscosity, reducing whey separation and binding free water[96], with their purposes differing from those used in cheese[97-98]. For instance, a mixture of gelling ingredients such as natural gums, proteins, starches, pectin, and agar can prevent syneresis and ensure the physical and microbiological stability of the product throughout its shelf life. These chemicals are generally utilised in food items more for their functional capabilities than their nutritional worth. There are, however, some health benefits associated with the addition of hydrocolloids, including weight- and CVD management (increases satiety, controls appetite, lowers serum cholesterol, as fat substitutes), immunomodulation (reduces allergy, improving immunogenicity, improving renal function, anti-genotoxicity, anti-cytotoxicity, anti-tumor), and gut health (soluble fibre and promoting probiotics)[99].

Due to the potential health benefits of CM, transforming CM into yoghurt can transfer these benefits and enhance them further through LAB fermentation (Table 4). In general, most studies have investigated the survival of probiotics and the synthesis of bioactive substances *in vitro*, with a lesser emphasis on *in vivo* research than dairy yoghurt. To qualify as probiotic yoghurt, a critical threshold of

Table 4
Use of LAB to produce fermented beverages or yoghurt for health purposes.

LAB	Purposes	Health outcomes	References
L. reuteri LR 92 or DSM 17938	Using statistical design to achieve optimal yoghurt parameters	Bioactive compounds were produced	[126]
L. bulgaricus and *L. acidophilus*	Production of yoghurt using different milk sources	The proximate values of CMBY were comparable with soy-, goat- and cow milk, but with the highest fat content	[127]
L. reuteri LR 92	Promoting greater viscosity, reducing syneresis, and improving health properties of CMBY with strawberry pulp	Improve probiotics viability and lauric acid contents	[94]
L. lactis MTCC 3041 + *Leuconostoc* sp. MTCC 10508 and *L. lactis* MTCC 3041 + *L. plantarum* MTCC 5422	Produced good quality *dahi* (Indian yoghurt) with dairy milk	The addition of sucrose reduced bitterness, and *L. plantarum* produced better-textured yoghurt	[128]
S. salivarus ATCC 13419 and K12	Evaluating the optimal probiotics in fermented CM	Increased carbohydrase and lipase activity	[129]
Kefir grains	Evaluating the biological activities of CM-based kefir (yoghurt-like)	Increase peptides and antioxidants content	[87]
L. acidophilus	Developing fermented PBM with cereals and legumes	Increased probiotics viability, antioxidant capacities, and polyphenol contents	[130]

10^6−10^7 CFU/mL is required to confer beneficial effects, or to survive the digestive systems[100]. This value can be challenging in plant-based yoghurts due to its lower acidification rate and slower probiotic growth, and longer fermentation period, due to limited sugar content. Since CM contains appreciable quantity of sugars as discussed previously, this problem might be mitigated, as demonstrated by the rapid pH reduction and the promotion of LAB growth observed in CM compared to dairy milk[101].

LAB in yoghurt is known to increase the production of some vitamins, such as vitamins B and K, and increase the bioavailability of certain minerals. LAB employed in fermentation has been demonstrated to boost Ca bioavailability in plant-based materials by 2.4-fold *in vitro*, followed by a considerable increase in bone-related properties *in vivo*[102]. Probiotic inoculation also increases the bioavailability of Ca through the production of readily accessible short-chain fatty acids in CM[103]. During fermentation, the organic

Table 5
Current CBMY in the USA market, it's nutritional labelling, and estimated price.

Name/Brand	Calories (kcal)	Sugars (g)	Proteins (g)	Fats (g)	Gelling agent	Price (USD)
 So Delicious CM Yogurt	110	< 1	< 1	7	Locust bean gum	
	97.35	**< 1**	**< 1**	**6.19**		**1.31/100 g**
 Siggi's Plant-Based Coconut Blend*	180	8	10	10	Tapioca starch, fruit pectin	
	120.00	**5.33**	**6.67**	**6.67**		**1.31/100 g**
 Harmless Harvest Dairy-Free Cup Yogurt	90	8	1	2	Tapioca starch, pectin	
	72.00	**6.40**	**< 1**	**1.60**		**1.82/100 g**
 Culina Organic Dairy-Free Yogurt*	220	9	2	16	Agar	
	154.93	**6.34**	**1.41**	**11.27**		**2.79/100 g**
 Oui by Yoplait	150	12	1	8	Tapioca starch	
	106.38	**8.51**	**< 1**	**5.67**		**1.39/100 g**
 Cocojune Coconut Yogurt	190	6	2	18	Cassava root	
	166.67	**5.26**	**1.75**	**15.79**		**1.74/100 g**
 Kite Hill Blissful Creamy CM Yogurt	130	1	1	7	Tapioca starch	
	120.00	**< 1**	**< 1**	**6.67**		**1.31/100 g**
 Cocoyo Coconut Yogurt	90	2	2	6	–	
	79.65	**1.77**	**1.77**	**5.31**		**2.84/100 g**
 Maison Riviera CM Yogurt*	120	0	4	7	Tapioca starch	
	68.57	**0**	**2.29**	**4**		**1.16/100 g**

Note: The data is extracted from https://www.godairyfree.org/product-reviews/dairy-free-yogurt-reviews. The price is accurate as of the date of publication. Unless otherwise specified, all yoghurts are plain CBMY with proprietary formulae of each company. The figures in bold are normalised to 100 g. *Fortify with additional plant proteins.

acid encourages the formation of soluble ligands that aid in the absorption of specific minerals, such as zinc and iron. Ca and other nutritive elements such as Mg, isoflavones, and vitamins such as vitamin B were detected in greater concentrations in PBM than in other plant-based foods[28]. This is an important point to note, as CM is generally low in Ca, especially in comparison to dairy milk. Therefore, by manipulating the CM with certain fortifications and fermentation processes, this substrate can be an excellent alternative to dairy yoghurt.

Some consumers can consciously limit their dietary intake based on certain beliefs. According to the popular website healthline.com, the top 10 nutritional restrictions are as follows: lactose intolerance, gluten sensitivity, vegetarianism, veganism, kosher/halal, keto, diabetes, dairy-free, low-carb, and allergies[104]. As plant-based yoghurt, CM fulfilled most of the dietary restrictions listed above. Although CMBY can have traces of allergens, fermentation of CM can lower the allergenicity of the proteins and allergic reactions by the action of proteolytic LAB while modulating immune responses[86]. The organic acids produced during yoghurt manufacture, such as lactic acid, can break the conformational structure of allergens and render them inert. Multiple pathways allow the LAB in yoghurt to influence or "re-educate" the host's type-1 T helper (Th1) and type-2 T helper (Th2) immune cells to improve allergy responses. Moreover, as the LAB internalise the substrate (and increase in population) for its biological functions, it will absorb the sugars and convert them into a variety of bioactive metabolites that are beneficial to health[86].

Table 5 lists a few CBMY available in the United States. In yoghurt with low-fat content, coconut water is used as the primary ingredient instead of CM. To boost their protein composition, manufacturers frequently combine them with other plant proteins, such as legume- or nut-based proteins. Likewise, the absence of proteins results in a lack of cross-linking and gelation capabilities, necessitating gelling agents (ideally from plant-based sources) while maintaining the dairy-free and vegan-friendly label. As indicated previously, the Ca content of non-dairy yoghurt is relatively low compared to dairy yoghurt (data not shown), and its presence is typically the result of fortification. Sugar and flavourings are frequently added to improve acceptability. Otherwise, the sugar level is typically minimal (below 1 g) due to LAB use. In addition, they usually contain more than 2 strains of LAB, most likely as a marketing strategy to attract health-conscious consumers since the gelling agents can provide the desired textural consistency. Nonetheless, the vast majority of CBMY is artisanal yoghurt with a limited market base; therefore, its availability is far more restricted.

Generally, different plant-based yoghurt will have different protein content, with the highest protein composition recorded in soy milk-based yoghurt[105]. Table 6 shows the general nutritional content of CMBY compared with commercial plant-based yoghurts and dairy yogurt in several countries[106]. The CMBY contain the most fats, predominantly saturated fats, which leads to an increase in calories. As some yoghurts are commercial, their production processes and proprietary recipes may influence their composition. Grasso et al.[90] discovered that among 6 yoghurts in Ireland, almond-based yoghurt contained the most fat and calories, followed by CMBY. However, both publications agreed that the protein content of CMBY tends to be the lowest, indicating fortifications are needed.

Table 6
Nutritional compositions of commercial plant-based yoghurts and dairy-based yoghurts.

Index	Dairy (n = 5)	Coconut (n = 32)	Soy (n = 16)	Almond (n = 12)	Oat (n = 8)	Cashew (n = 5)
Energy (kcal/100 g)	74.34	114.39	61.82	83.98	72.19	74.27
Carbohydrates (%)	5.27	5.55	4.81	6.45	9.51	5.86
Total sugars (%)	5.16	1.68	3.7	1.81	1.87	0.75
Fiber (%)	0	1.22	1.12	2.03	0.88	2.59
Protein (%)	4	1.53	4.2	2.41	1.81	1.78
Total fat (%)	3.92	9.8	2.51	5.41	3.19	4.85
Saturated fat (%)	2.48	8.5	0.4	0.57	1.57	1.04

Note: Data is derived from the supplementary materials by Boeck et al.[106].

6. Future direction on improving CMBY

Yoghurt is enjoyed around the world as a highly nutritious breakfast, snack food, and dessert. The substrate (CM), probiotics (LAB), and flavorings/toppings can be prioritised to increase nutritional characteristics and further improve its health benefits. To manufacture a CBMY that is nutrient-dense and safe, the appropriate substrate must be screened, as this will define the yoghurt's final nutritional qualities. Depending on the type and maturity of coconut, it is possible to consider a CM rich in protein and Ca but low in allergens and heavy metals.

The LAB employed in yoghurt preparation is necessary to aid in the creation of milk protein gels. As previously noted, the synthesis of organic acids and specific proteolytic enzymes can modify the characteristics of milk proteins and induce them to be aggregated. Due to the low protein composition of the CM, the LAB related to protein coagulation are of lesser importance. However, LAB is still required to lower pH and promote overall health as a probiotic. A superior method is to screen Generally Recognised as Safe (GRAS) LAB for lipolytic activity (lipase and esterase). These enzymes can contribute to the production of aroma and flavour by altering the structure or content of fatty acids. According to a recent study by García-Cano et al.[107], 50.3% of 137 LAB in the dairy product produced extracellular lipolytic activity, which adds to textural changes[107] and health properties[108]. In cheese, the esterase activity by LAB improved the fruity flavor[109] and increased the free fatty acids composition[110].

Secondly, the use of LAB strains which can produce good amino acid quality is important to consider in the yoghurt production process. In a recent review by Kobayashi[111], the author stated that numerous LAB could convert *L*-amino acids into the more uncommon *D*-amino acids. These *D*-enantiomers can serve as bioactive chemicals, such as *D*-serine (a neurotransmitter) and *D*-aspartate (a hormone-like molecule), while simultaneously enhancing the sweetness of yoghurt without increasing its sugar level. Given the significant benefits of CBMY for the brain and its ability to reduce the risk of cardiovascular disease, it is highly desirable to identify the LAB strains that may produce more neurotransmitters with low sugar content. It was discovered that these LAB possess a specific gene segment that codes for *D*-amino acid-metabolizing enzymes[111].

As CM is low in Ca and acceptance, fortification in form of flavoring can be considered to achieve a good dairy alternative. To be more natural, additives from plant-based materials are desirable[112-113]. For example, certain vegetables such as *Cosmos caudatus* and water spinach contain an excellent amount of Ca and can easily be cultivated as they possess weed-like characteristics and grow in abundance[114]. Or perhaps, the coconut meat itself can be incorporated into the CBMY. The coconut meat can be calcium-rich, containing up to 14 mg of calcium per 100 g. Other minerals include P (113 mg), K (356 mg), and Mg (32 mg). Additionally, it is rich in dietary fibre, amino acids, and certain vitamins (FDC ID: 170169)[115]. In Southeast Asia, adding coconut meat to the agar formulation of coconut drink (locally known as jeli kelapa or coconut jelly) is quite popular since it offers contrasting texture and flavour to the base formulation. The concept imitates the popularity of bubble tea in Asia by enhancing organoleptic qualities with contrasting toppings.

Due to the negative health perceptions of CM, some manufacturers may use low-fat CM rather than full-fat CM, as is the case with dairy yoghurt. Despite the fact that the full-fat version has more calories, a cohort study of 3 333 adults over 15 years revealed that those who had full-cream milk had a 46% decreased chance of getting diabetes. The author argued that the shortage of calories in the low-fat version caused an increase in the consumption of other macronutrients, particularly carbohydrates[116]. In another cohort study of 18 438 women, the person who consumed full-fat milk had, on average 8% lower risk of developing obesity[117]. As a result, full-fat CM can lead to several health benefits related to the consumption of coconut oil[43,118].

To attain complete circularity, fruit, and vegetable waste may be employed as condiments or flavourings. Especially for those with attractive colours, such as mangosteen or dragonfruit peel, and grape pomace, this fruit waste can contribute to the CBMY's colour while strengthening it with Ca and other nutrients[119-120]. According to FoodData Central by USDA (FDC ID: 171688 and FDC ID: 171689; a comparison of an apple with and without skin), the fruit peel can contain a significant amount of Ca[115]. The pigments of these bright-coloured fruit skins are commonly rich in anthocyanins, betalains, carotenoids, and chlorophylls that can contribute to vast therapeutic effects, such as antioxidants, anti-inflammatory, anti-microbial, anti-cancer, and cardioprotective effects[121].

7. Conclusion

As the global populations continues to grow, strong consumer interest in sustainably sourced PBM provides an opportunity to investigate the potential of CM, as an excellent alternative to dairy milk, with a focus on yoghurt production. The health benefits of CMBY derives its strength from the MCFA and plant-based phytochemicals, which are powerful tools to manage oxidative-stress-related disorders. There is much evidence demonstrating the promising health outcomes of consuming CMBY. However, as with other foods, moderation and access to a diverse diet is key and overconsumption of a particular food type can lead to undesirable outcomes.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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