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Systematic Review Article

Dark Chocolate: A Review on the Effect of Functional Ingredient Substitution on Physicochemical Properties, Sensorial Acceptance and Potential Health Benefits

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ABSTRACT

This scoping review aimed to evaluate evidence from 2013 to 2024 on the impact of substituting functional ingredients in dark chocolates in terms of their physicochemical properties, sensory acceptance, and potential health benefits. A literature search was performed using electronic databases including PubMed (National Library of Medicine), Science Direct (Elsevier), and Scopus (Elsevier), using data from 2013 to 2024. All types of studies published in English, excluding systematic reviews or review papers, were eligible for inclusion. A total of 1,067 eligible studies were identified, 24 of which met the inclusion criteria. This review highlights trends and existing gaps, and provides valuable insights for researchers, industry professionals, and consumers interested in chocolate formulation and consumption. The findings indicate that incorporating functional ingredients, such as fibres, polyphenols, and probiotics, can enhance the nutritional profile of dietary fibre, antioxidant activity, and gut health effect from dark chocolate. However, these substitutions are negatively affected by decreasing physical properties (e.g., hardness, viscosity, and melting temperature) and sensory attributes such as flavour and texture. This review shows that, although substituting functional ingredients improves nutritional quality, it negatively affects sensory characteristics and poses a significant challenge to consumers. Further research should explore novel ingredients to optimise nutritional profiles, increase health benefits, and improve sensory attributes of chocolate products.

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INTRODUCTION

Chocolate consumption has increased globally (0.5 kg per person annually in Malaysia), slightly more than in the Philippines and Indonesia (0.3 kg), but far less than in Switzerland (8.8 kg) (Durai 2022; Del Prete & Samoggia 2020). In line with this upward trend, global cocoa production rose from 1.6 million tonnes in 1980–1981 to nearly 5 million tonnes by 2018–2019, with Ivory Coast and Ghana accounting for 60% of the total output.

Dark chocolate has gained attention for its health-promoting properties, largely due to its high content of bioactive compounds, such as polyphenols, flavonoids, procyanidins, and theobromine (Ashfaq *et al.* 2024). These compounds contribute to its classification as a functional food with demonstrated anti-diabetic, anti-inflammatory, antioxidant, and antimicrobial effects (Samanta *et al.* 2022). Dark chocolate contains five times the concentration of polyphenols and flavonoids compared to milk chocolate (Fanton *et al.* 2021). In addition, dark chocolate (67% cocoa) exhibited the highest total polyphenol content and antioxidant activity, followed by semisweet chocolate (43% cocoa), soy chocolate, and milk chocolate (da Silva Medeiros *et al.* 2015). Flavonoids in dark chocolate have been reported to have positive effect in lowering blood pressure and supporting immune function (Latif 2013).

In response to increasing consumer demand for health-oriented food products, recent research has focused on enhancing the nutritional profile of dark chocolate by incorporating functional ingredients such as natural sweeteners, microencapsulated phytosterols, collagen

hydrolysate, dietary fibres, and probiotics (Ashrafie *et al.* 2014; Akyol *et al.* 2014; Tolve *et al.* 2018; Nurhayati *et al.* 2022). These additions have the potential to reduce the risk of non-communicable diseases. Although dark chocolate is often viewed as the healthiest chocolate type, its sugar content remains a concern because of its association with obesity, cardiovascular issues, and elevated blood glucose levels. Natural alternatives such as agave nectar and stevia not only offer lower glycaemic responses but also exhibit antioxidant and antibacterial activities (Mellado-Mojica & Lopez 2015). However, the incorporation of such ingredients may alter key physicochemical attributes such as texture and taste, potentially affecting consumer acceptance (Galanakis 2021).

Physicochemical properties and sensory acceptance of dark chocolate are key indicators of its quality and consumer appeal. Processing steps such as fermentation, roasting, grinding, and conching, significantly influence viscosity, texture, and nutrient content (Afoakwa 2014). Prolonged processing can result in significant nutrient loss, with polyphenol content dropping almost 10 times from its original form. To mitigate the large loss of phytonutrients, fortification and enrichment with functional ingredients have been shown to preserve phytonutrients and enhance colour, aroma, and overall quality (Samanta *et al.* 2022). This approach may contribute to maximising the therapeutic potential of dark chocolate.

This scoping review aims to summarise the available evidence regarding the effects of functional ingredients incorporated into dark chocolate, specifically focusing on their impact on physicochemical properties, sensory acceptance, and health benefits. The insights gained from this review will help guide future research efforts, facilitating the development of dark chocolate products that maximise both sensory appeal and health-promoting properties.

METHODS

Material and tools

The present study was conducted as a scoping review to assess the effects of substituting chocolate ingredients on the physicochemical properties, sensory acceptance, and potential health benefits. The review followed the five-stage methodological framework outlined by Tricco *et al.* (2018), which included: (1) identifying the research questions, (2) identifying relevant studies, (3) selecting studies, (4) charting the data, and (5) collating, summarising, and reporting the results. The guidelines used to record the review process were based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PRISMA flow diagram illustrates the flow of articles from the initial search to final selection (Figure 1).

Identifying the research question

The research questions for this scoping review were as follows: (1) What are the effects of chocolate ingredient substitution on physicochemical properties? (2) What is the effect of chocolate substitution on sensory acceptance? (3) What are the beneficial health effects of dark chocolate containing substituted functional ingredients, and the extent to which its clinical effectiveness has been explored?

Identifying relevant literature

Academic journals (in English) published between 2013 and 2024 were identified through an electronic database search using PubMed, Scopus, ScienceDirect, and Google Scholar. The search included all study types except systematic reviews and review papers. The researchers independently screened the titles, abstracts, and keywords for eligibility. Eligible study designs

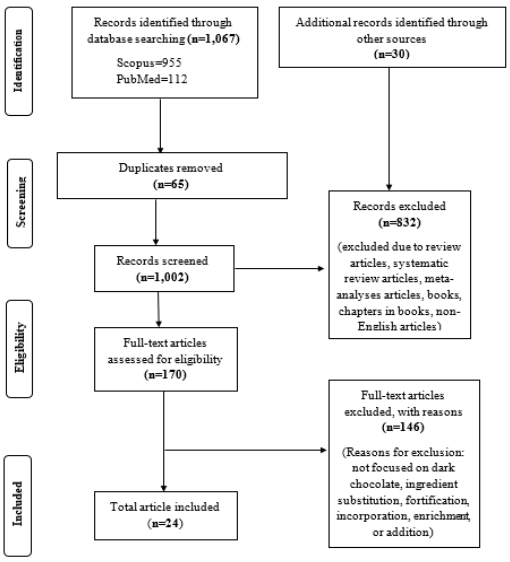

Figure 1. PRISMA (preferred reporting items for systematic reviews and meta-analyses) flow diagram of study selection

for this scoping review included randomised controlled trials, crossover intervention trials, and observational studies that specifically examined the effects of chocolate substitution on physicochemical properties, sensory acceptance, and associated health benefits. Studies that did not meet the selection criteria, were unrelated to the research questions, or were duplicate publications were excluded. The inclusion criteria for the articles were as follows: research articles published in peer-reviewed journals, written in English, and published between 2013 and 2024. Eligible study types included in vitro studies, human clinical trials, and observational studies. Articles were excluded if they were systematic reviews, books, book chapters, conference proceedings, written in languages other than English, or published before 2013. Animal studies were also excluded. Additionally, several full-text references were reviewed as supplementary material. A total of 24 studies were included in this review, out of the 1,067 studies identified through electronic databases.

Selecting literature

The full references of the articles retrieved from the databases were downloaded and manually entered into Excel. Two reviewers independently screened the articles according to the inclusion and exclusion criteria and any discrepancies were resolved by a third reviewer. A total of 1,067 articles were identified; 30 duplicates were removed, 1,002 titles and abstracts were screened based on the inclusion and exclusion criteria, and a total of 24 articles were read in full text. The article selection process is illustrated in Figure 1.

Charting data

A narrative and analytical approach was employed to extract data from studies that best aligned with the research aims following the framework of Tricco *et al.* (2018). The Mendeley programme was used to record and export articles identified through electronic databases. Subsequently, duplicate entries were removed, and the remaining full-text articles were assessed for eligibility. The eligibility process requires determining the criteria for inclusion and exclusion. After removing full-text articles that did not meet the criteria, the remaining data were included in this scoping review. Comments, letters, conference abstracts, reviews, short communications, meta-analyses, and animal studies were excluded. The data are presented according to author(s), year of publication, country, study design, substitution approach (functional ingredients), dose or amount (formulation of dark chocolate), and main outcomes.

Collating, summarising, and reporting results

The significant findings and data from this review are summarised in Table 1, Table 2, Table 3 and have been adjusted to meet the objectives of the study. The elements extracted from the findings focus on variables concerning physicochemical properties, sensory acceptance, and beneficial health effects related to dark chocolate and its ingredient substitution. This table was designed to assist in the synthesis of the included studies.

RESULTS AND DISCUSSION

Study characteristics

A total of 24 publications that met all the inclusion and exclusion criteria were included in the final review. These studies were conducted in various countries. The majority were conducted in the UK (4) and Iran (3), followed by Indonesia (3), Turkey (2), Italy (2), and India (2). One study was conducted in Belgium, while the remaining were conducted in Malaysia, Peru, Denmark, Portugal, Brazil, the United States (California), and Poland. As shown in Table 1, Table 2, and Table 3, 24 selected studies examined the effects of dark chocolate on physicochemical properties, sensory acceptance, and associated health benefits. Two focused on cardiovascular risk in obese and overweight, one on cardiovascular function and platelet aggregation, one on short-term satiety and energy intake, one on the gut microbiome and its effects on liver metabolism, skeletal muscle, and skin in moderately obese individuals, one on endogenous metabolism, and one on In Vitro gastric passage and sensory analysis. Thirteen studies addressed physicochemical properties and sensory acceptance, while three focused on physicochemical properties and microbiology. Additionally, one study explored sensory and emotional conceptualisation.

Effects on physicochemical properties

Sixteen studies investigated the effects of functional ingredients on the physicochemical attributes of dark chocolate, including texture,

Table 1. Effects of DC and its Functional ingredients on physicochemical properties

Author and country	Functional ingredients	Treatments/Dose/Amount (Formulation of DC)	Main outcomes (Physicochemical properties)
Akdeniz *et al.* (2021) Turkey	**Substitution** (Cocoa Substitute) Carob powder	DC1: Control DC2: 20% Carob powder DC3: 40% Carob Powder DC4: 60% Carob Powder DC5: 80% Carob Powder DC6: 100% Carob powder	**Color** DC2: ↑ a*, Chroma (brighter); DC3–DC4: slight ↓ a*, Chroma; DC5: further ↓; DC6: marked ↓ (darker). **Hardness** ↑ Carob → ↑ hardness, DC6: ↓ hardness (due to larger particles & fiber). **Mean particle size** ↑ Carob → ↑ particle size (coarser texture), DC1–DC3: ↓ size, DC4–DC6: ↑ size. **Rheological** ↑ Carob → ↑ viscosity, ↓ yield stress in dark chocolate (easier flow) ↑ yield stress in milk chocolate at high carob (initially thicker, easier flow later)
Vahedi & Mousazadeh (2016) Iran	**Substitution** (Sugar Substitute) Stevia and Agave Nectar	DC1: 0% S, 0% A, 100% St DC2: 0% S, 25% A, 75% St DC3: 0% S, 50% A, 50% St DC4: 0% S, 75% A, 25% St DC5: 0% S, 100% A, 0% St DC6: 33.3% S, 33.3% A, 33.3% St DC7: 50% S, 25% A, 25% St DC8 (Control): 100% S, 0% A, 0% St	**Moisture & water activity** Stevia: ↑ moisture & water activity Agave: similar water activity to sucrose, but ↑ moisture retention. **Fat & protein content** ↑ Stevia: ↑ fat & protein , ↑ Agave Nectar: ↓ fat & protein **Color properties (hue & chroma)** ↑ Stevia: ↑ brightness (L*) ↑ Agave: ↓ brightness (darker, Maillard reaction). Hardness Sucrose: ↑ hardness (control), Stevia & Agave: ↓ hardness (softer texture). **Rheological properties** Sucrose: ↑ yield stress & viscosity (highest), Agave: ↑ yield stress & viscosity (moderate) Stevia: ↓ viscosity (easier processing)
Tolve *et al.* (2018) Italy	**Fortification** MP DC	DC1: 64% Cocoa + (0, 5, 10,15)% MP DC2: 72% Cocoa + (0, 5, 10,15)% MP DC3: 85% Cocoa + (0, 5, 10,15)% MP	**Particle size distribution** ↑MP → ↑ Particle size: ↑ coarse particles (D90), but still below 25 µm, suitable for chocolate texture. **Peroxide value (Oxidation)** Stable (0.679–2.545 meq O_2/kg fat) — low oxidation after 3 months **Antioxidant activity** ↑ MP & 85% cocoa mass → ↑ activity (up to 92 µg trolox/g). Color (L*) ↑ MP → ↑ lightness over time (brighter appearance). **Moisture content & water activity** MP had no significant effect over 3-month storage **Bioaccessibility** Low phytosterol bioaccessibility (3.3% gastric, 8.4% intestinal)
Gallegos Soto *et al.* (2020) Brazil	**Substitution** (Fat substitute) Complex Chitosan Hydrogels with addition Canola oil	DC1:CC DC2: RFC	**Fat reduction** RFC: 16% ↓ saturated fat by replacing 80% cocoa butter with hydrogel (20% canola oil) **Oil retention** ↑ with CHI-based hydrogels. Viscosity & Rheology DC2 (RFC): ↑ viscosity (3.06 vs. 1.95 Pa•s in CC), within acceptable range (2–4 Pa•s). Yield stress: RFC ↑ initially, ↓ over time; CC remained stable. **Texture (snap test)** DC1 & DC2: Similar snap strength; CC showed more variation during storage. **Melting profile** DC2 (RFC): Slightly ↑ melting temp, indicating stable polymorph; similar melting behavior to CC. **Nutritional profile** RFC: ↓ calories (523.3 vs. 550.7 kcal/100 g in CC) & 16% ↓ saturated fat - a healthier alternative.

Continue fromTable 1

Author and country	Functional ingredients	Treatments/Dose/Amount (Formulation of DC)	Main outcomes (Physicochemical properties)
Ashrafie *et al.* (2014) Iran	**Substitution** (Fat substitute) collagen hydrolysate	DC1 (Control): 330 CB + 0 IGS DC2: 280 CB + 50 IGS DC3: 264 CB + 66 IGS DC4: 247.5 CB + 82.5 IGS DC5: 230 CB +100 IGS	**Chemical composition** ↑ Collagen Hydrolysate → ↑ Protein (143%), ↓ Fat (20%), ↓ Energy (54%) **Rheological properties** Hardness ↑ as ↓ Fat ↑ Collagen Hydrolysate & ↓ CB → ↑ Viscosity, ↑ Plastic Viscosity, ↑ Thixotropy
Monteiro *et al.* (2023) Portugal	**Incorporating** Baobab Pulp	DC1 (Control): 0% Baobab pulp DC2: 3% Baobab pulp DC3: 6% Baobab pulp DC4: 9% Baobab pulp	↑ Baobab Pulp Flour → ↑ Antioxidant Activity, ↑ Vitamin C, ↑ Calcium, ↑ Potassium, ↑ Phosphorus, ↑ Chlorine, ↑ Sulphur, ↑ Moisture, ↑ Ash, ↑ Red Colour Intensity, ↑ Yellow Colour Intensity **Fat, protein, and hardness:** No significant changes. **Fatty acids:** No changes except for C20:1 (cis 11) at 6% and 9%
Kobus-Cisowska *et al.* (2019) Poland	**Enrichment** *Bacillus coagulant*s	DC1: 10^6 CFU g−1 *Bacillus coagulans* DC2:10^7 CFU g−1 *Bacillus coagulans* DC3: 10^8 CFU g−1 *Bacillus coagulans*	↑ ***Bacillus coagulants*** → ↑ Polyphenol Content (initial), ↓ Polyphenol Content (15.9% after 24 months) ↓ Catechin & Epicatechin (45% after 24 months), ↑ Epigallocatechin Gallate Stability, ↑ pH, ↓ Water Activity (aw), ↑ Bacterial Count (up to 2.2 × 10^10 CFU/g), ↑ Survivability (best at 4°C for 24 months).
Yoriska et al. (2019) Indonesia	**Enrichment** Kaffir lime (*Citrus hystrix* DC.) leaf essential oil	DC1: DC + 0.25% Kaffir lime leaf essential oil DC2: DC + 0.50% Kaffir lime leaf essential oil DC3: DC + 0.75% Kaffir lime leaf essential oil	**Color** No visual difference across samples, ↑ °Hue at higher EO levels (F2, F3 → darker). **Texture (hardness)** ↑ EO concentration → ↓ hardness, softest at 0.75%. **Moisture content** ↑ Kaffir lime essential oil → ↑ Moisture content compared to the control. **Antioxidant activity** 0.25% kaffir lime essential oil → Significant increase in antioxidant activity.
Handiati *et al.* (2019) Indonesia	**Incorporation** *Kaempferia galanga* L. essential oil	DC1: DC + 0.1 % *Kaempferia galanga* L. rhizomes essential oil DC2: DC + 0.2 % *Kaempferia galanga* L. rhizomes essential oil DC3: DC + 0.3 % *Kaempferia galanga* L. rhizomes essential oil	↑ *Kaempferia galanga* L. essential oil → ↓ Hardness (Lowest at 0.3% concentration) ↑ *Kaempferia galanga* L. essential oil → No Significant Effect on Colour, Taste, Texture, Glossiness, Melting, and Overall Preference
Nurhayati *et al.*(2022) Indonesia	**Enrichment** Probiotic **Substitution** palm sugar and coconut sugar	DC1: Choc sucrose DC2: Choc coconut sugar DC3: Choc palm sugar	**Viscosity** DC2 > DC1 > DC3 (lowest). **Melting temperature** DC1: ↓melting temperature. DC2 & DC3: ↑ melting temp (linked to ↑ moisture & viscosity). **Antioxidant activity** DC3: ↑ antioxidant vs. DC1 & DC2, but still <BHT & BHA ; TPC: DC3 > DC2 > DC1 **Calorie value** ↓ Calorie content D3 < Coconut/Sucrose **Probiotic viability** All samples: 6.88–7.16 log CFU/g — meets probiotic threshold. (Chocolate is effective probiotic carrier) **Colour** DC3 & DC2: darker > DC1 (Maillard reaction). **Surface microstructure** DC2 & DC3: more sugar agglomeration (↑ hygroscopicity) than DC1. **Functional food potential** Palm sugar: promising for glycemic control→ Further study needed

Continue from Table 1

Author and country	Functional ingredients	Treatments/Dose/Amount (Formulation of DC)	Main outcomes (Physicochemical properties)
Didar (2021) India	**Enrichment** vitamin D3 (free or liposome)	DC1: Control Sample DC2 : DC fortified with free vitamin D3 DC3: DC fortified with liposome-encapsulated vitamin D3	**Liposome preparation** Ethanol injection method → ↑ vitamin DC3 loading efficiency (62.6 ± 1.2%). **Vitamin DC3 stability** DC3: stable up to 70 days, DC2: degradation after 60 days. **Quality parameters** DC2 & DC3: No significant effect on color, Casson viscosity, or melting profile (onset, peak, enthalpy)
Erdem *et al.* (2014) UK	**Enrichment** *Bacillus indicus* HU36, maltodextrin and lemon fiber	DC1–DC11: MD/LF (g/100g) ranged from 1.5–5.5 each	↑ *Bacillus indicus* HU36 in chocolate → 88-91% Survival Rate ↑ Dietary Fiber Addition → ↑ brightness (without affect dark Appearance) ↑ Synbiotic Chocolate → ≥5 log cfu/g Probiotic Viability
Didar (2020) Iran	**Enrichment** Free and encapsulated chlorogenic acids extracted from green coffee	D1–D6: Dark chocolate with 0–50 mg/5 kg free chlorogenic acids (A0–A5) D7–D11: Dark chocolate with 10–50 mg/5 kg encapsulated chlorogenic acids (AE1–AE5)	↑ Encapsulated chlorogenic acids → ↑ Casson viscosity & ↑ lightness (L)* ↓ Free chlorogenic acids → ↓ Onset temperature (Tonset), peak temperature (Tpeak), & enthalpy (ΔH) ↑ Encapsulated chlorogenic acids → ↑ Particle size compared to free form.
Balcázar-Zumaeta *et al.* (2022) Peru	**Fortification** FDAP	DC1: 70% DC with no FDAP (control) DC2: 70% DC + 1% FDAP DC3: 70% DC + 1.5% FDAP DC4: 70% DC + 2% FDAP	↑ FDAP → No significant change in TPC, AC, catechin, or epicatechin (DC2–DC4 compared to control) ↑ Casson yield stress (16.16 → 19.67 Pa in DC4) ↓ Plastic viscosity (2.15 → 1.68 Pa•s) **No effect on moisture or hardness** ↑ Particle size (D90: 15.71 → 67.84 µm) No functional improvement in 70% dark chocolate
Prasep-tiangga *et al*. (2019) India	**Addition** CBOM	DC1: DC (control) DC2: DC+ 4% CBOM DC3: DC + 6% CBOM DC4: DC + 8% CBOM	↑ **CBOM (DC4)**: ↑ TPC & antioxidant activity, ↑ Hardness, ↑ Lightness (L*) & hue (reddish tone) No change in moisture, GC-MS: ↑ tocopherol, methylxanthines (theobromine, caffeine), & cinnamaldehyde
Koh *et al.* (2023) Malaysia	**Enrichment** GABA	DC1: (Control) DC2: DC+ 0.05% GABA DC3: DC + 0.10% GABA DC4: DC+ 0.15% GABA	↑ GABA content & ACE inhibition (potential BP regulation) ↑ Hardness (highest in DC4) No significant change in viscosity or melting (similar pseudoplastic flow)

AC: Antioxidant Capacity; ACE: Angiotensin Converting Enzyme; BHA: Butylated Hydroxyanisole; BHT: Butylated Hydroxytoluene; BP: Blood Pressure ; CB: Cocoa Butter; CBOM: Cinnamon (*Cinnamomum burmannii*) Bark Oleoresin Microcapsule; CC: Control Chocolate; DC: Dark Chocolate; EO: Essential Oils; FDAP: Freeze-Dried Arazá (*Eugenia stipitata*) Pulp; GABA; Gamma-Aminobuytric Acid; IGS; MP: Microencapsulated Phytosterols; RFC: Reduced Fat Chocolate TPC: Total Polyphenol Content

melting point, crystallisation, and nutrient composition. Several studies observed that incorporating novel ingredients led to minor or no significant changes in fat, protein, or hardness levels while enhancing antioxidant capacity or nutrient profiles (Ashrafie *et al.* 2014; Monteiro *et al.* 2023; Koh *et al.* 2023). Tolve *et al.* (2018) reported an increase in the mean particle size of chocolate when incorporating microencapsulated phytosterols, although the particle size remained within acceptable quality limits (>25 µm). Supporting this, Glicerina *et al.* (2014) emphasised that the optimal chocolate texture is linked to a bimodal particle size distribution, where the majority of particles fall below 35 µm. Conversely, Akdeniz *et al.* (2021) found that increasing the amount of carob powder in the formulation led to a higher mean particle size, resulting in an undesirable coarse texture. Feichtinger *et al.* (2020) noted that dispersed particles, which make up approximately 65–70% of chocolate by weight, play a crucial role in determining rheological behaviour because their interactions within the fat matrix significantly influence texture and flow. These findings highlight how specific ingredients affect structural attributes, particularly particle size, which plays a critical role in final product quality.

Several studies have reported improvements in nutritional and antioxidant

profiles with the addition of functional ingredients. For instance, Monteiro *et al.* (2023) and Koh *et al.* (2023) demonstrated that baobab pulp and other bioactive compound-rich materials enhance mineral content and antioxidant capacity with minimal impact on macronutrient levels. Similarly, cinnamon bark oleoresin and Gamma-Aminobutyric Acid (GABA)-enriched formulations increased antioxidant activity and hardness, while preserving desirable processing characteristics (Praseptiangga *et al.* 2019; Koh *et al.* 2023). Fat-reduction strategies using protein-based replacers or chitosan hydrogels with canola oil lowered the energy content and improved the rheological behaviour without compromising texture (Ashrafie *et al.* 2014; Gallegos Soto *et al.* 2020). Notably, Gallegos Soto *et al.* (2020) achieved a 16% fat reduction while maintaining traditional snap properties, underscoring the potential of fat alternatives that uphold consumer-perceived quality.

Vahedi and Mousazadeh (2016) reported that stevia and agave nectar increased the moisture content, with agave nectar demonstrating superior water retention, lower water activity, and notable effects on fat, protein, and viscosity. Similarly, Nurhayati *et al.* (2022) observed that chocolates sweetened with coconut and palm sugars had higher viscosity and melting temperatures than those sweetened with sucrose, with palm sugar yielding the greatest antioxidant activity and lowest caloric content, although still less potent than synthetic antioxidants. The greater viscosity was attributed to natural impurities, such as minerals and reducing sugars. This supports the findings of Saputro *et al.* (2020), who reported that impurities in coconut and palm sugar, such as proteins, minerals, and reducing sugars, contributed to increased viscosity and enhanced antioxidant activity in chocolate. However, the long-term health implications of such substitutions require further study. These findings underscore the potential of natural sweeteners to improve thermal stability while maintaining key textural properties, positioning them as valuable alternatives in chocolate production for both health and structural benefits

Probiotic fortification-maintained viability (≥88%) and enhanced textural and sensory properties without altering colour or stability (Erdem *et al.* 2014; Kobus-Cisowska *et al.* 2019). In addition to probiotic, microencapsulation techniques have been used to preserve bioactive compounds such as chlorogenic acids and vitamin D3, stabilising their presence without affecting melting point or viscosity (Didar 2020; Didar 2021). Functional additions, such as cinnamon bark oleoresin and GABA, increased antioxidant activity, hardness, and bioactive compound content while maintaining acceptable processing properties and shelf stability (Praseptiangga *et al.* 2019; Koh *et al.* 2023). Other formulations, including carob powder and freeze-dried arazá pulp, led to increased particle size and viscosity, with limited impact on antioxidant or polyphenol content (Akdeniz *et al.* 2021; Balcázar-Zumaeta *et al.* 2022). Similarly, essential oils from Kaffir lime and Kaempferia galanga L. improved antioxidant profiles, although higher concentrations slightly reduced the hardness. Despite this, sensory attributes such as colour, glossiness, taste, and melting properties remained unchanged, indicating that these oils can enhance health benefits without compromising appeal (Yoriska *et al.* 2019; Handiati *et al.* 2019).

Overall, the current evidence suggests that incorporating functional ingredients can improve the nutritional and antioxidant properties of dark chocolate while preserving its core physicochemical and sensory characteristics. However, certain ingredients that increase viscosity or particle size may introduce challenges in formulation and processing. Future research should focus on determining the optimal levels and combinations of ingredients to achieve a balance between health benefits, product quality, and manufacturing efficiency.

Effects on sensory acceptance

Sensory acceptance plays a vital role in the market success of dark chocolates, as consumer preferences for taste, texture, aroma, and overall satisfaction are key to product viability. In addition to physicochemical characteristics, the impact of functional ingredients on sensory attributes has been the central focus of many studies. However, maintaining desirable sensory qualities becomes challenging when functional ingredients are introduced, especially given the inherent bitterness and astringency of dark chocolate owing to its high cocoa content.

Sixteen studies evaluated the sensory acceptance of dark chocolates enriched with various functional ingredients, focusing on taste, texture, aroma, and overall preference. Vahedi and Mousazadeh (2016) found that while the use

Table 2. Effects of DC and its functional ingredients on sensorial acceptance

Author and country	Study design	Functional ingredients	Main outcomes (Sensory acceptance)
Akdeniz *et al.* (2021) Turkey	n=27, trained panelists, 5-point Hedonic Scale	**Substitution** (Cocoa Substitute) Carob powder	↑ Carob powder ↓ Sensory Scores (Darker color, coarser texture) DC2 & DC3 Similar sensory acceptance to control. DC4, DC5 & DC6 ↓ Acceptability (especially in milk chocolate)
Vahedi & Mousazadeh (2016) Iran	n=16, (age 20-40 years) 5-point Hedonic Scale	**Substitution** (Sugar Substitute) Stevia and Agave Nectar	↑ Agave Nectar: Highest sensory scores for flavor, taste, and overall acceptability. ↑ Stevia: Lower sensory scores, especially in texture and melting in the mouth
Tolve *et al.* (2018) Italy	**Sensory test** n=116 (6 Female & 6 males), trained panellist, (age 21−32 years), Quantitative Descriptive Analysis for 20 sensory attribute **Consumer test** n=12 (65 females & 51 male),Regular chocolate consumer, (age 18−64 years), 9-point hedonic scale	**Fortification** MP DC	↑ MP → ↓ Grittiness, Enhanced Smoothness: No significant effect on sensory attributes like sweetness and bitterness. 85% Cocoa + MP → ↑ Consumer Acceptability when informed about health benefits
Gallegos Soto *et al.* (2020) Brazil	n=120, untrained panelists (age >18 years) 9-point hedonic scale	**Substitution** (Fat substitute) Complex Chitosan Hydrogels with addition Canola oil	No Significant Difference in Overall Acceptability: Sensory analysis showed no significant difference between RFC and CC in terms of appearance and flavor. However, RFC was slightly less preferred in terms of sweetness and mouthfeel
Ashrafie *et al.* (2014) Iran	n= 15, staff of the Rezvan Chocolate Company (Karaj, Iran), ranking method (age 20−47 years)	**Substitution** (Fat substitute) collagen hydrolysate	No significant differences (color, taste, mouthfeel, sweetness, hardness, texture) between the chocolate samples and the control. Best Replacement Level:Best Replacement (200 g•kg−1 CB) with improved chemical, rheological, and sensory characteristics → ↓ Fat (11.1%), ↓ Energy (35.8%), ↑ Protein (82%)
Monteiro *et al.* (2023) Portugal	n= 21, untrained panellist, 5-point hedonic scale	**Incorporating** Baobab Pulp	↓ Sensory Evaluation (at 9% baobab), ↑ Sensory Evaluation (at 3% baobab)
Kobus-Cisowska *et al.* (2019) Poland	n=16, Trained panellists 10 cm-long line scale with adequate edge captions (intense/not intense)	**Enrichment** *Bacillus coagulants*	No significant change in taste or texture, except a slight ↓ in chocolate and spicy taste
Yoriska *et al.* (2019) Indonesia	n=30, random panellist, (ages 20−22 years) 5-point Hedonic Scale	**Enrichment** Kaffir lime (*Citrus hystrix* DC.) leaf essential oil	Highest acceptance with 0.25% kaffir lime leaf essential oil (F1) for aroma, taste, and overall. ↓ Acceptance at 0.5% and 0.75% concentrations due to stronger bitter taste and aroma
Handiati *et al.* (2019) Indonesia	Completely Randomized Design n=30, (age 21−24 years), 5-point Hedonic Scale	**Incorporation** *Kaempferia galanga* L. essential oil	↑ *Kaempferia galanga* L. essential oil (0.3%) → ↑ Aroma Preference (Highest panelist acceptance)
Marcial-Coba *et al.* (2019) Denmark	n=17, untrained panelists (aged 25-47 Years), from different nationalities (9-point hedonic scale)	**Fortification** *Akkermansia muciniphila* and *Lactobacillus casei.*	↑ Hedonic sensory test → No significant differences in taste and mouthfeel compared to commercially available chocolates
Didar (2020) Iran	n=10, Trained panelists, 7-point hedonic scale	Enrichment Free and encapsulated chlorogenic acids extracted from green coffee	↑ Encapsulated chlorogenic acids → Better sensory properties (appearance, texture, flavor) than free form DC7 & DC8, ↑ sensory score (Acceptability, appearance & Texture) ↓ Free chlorogenic acids → ↓ Blooming and ↑ Bitterness in dark chocolate, ↓ sensory Scores

Continue from Table 2

Author and country	Study design	Functional ingredients	Main outcomes (Sensory acceptance)
Didar (2021) India	n=10 trained panelists **Study duration (Storage Study):** (0, 15, 30, 45, 60, and 70 days)	**Enrichment** vitamin D3 (free or liposome)	no significant in acidity, bitterness, sweetness, cocoa taste, smoothness, or melting
Erdem *et al.* (2014) UK	RSM **Pre-test (Fiber)** n= 10, (6 females & 4 males, (25−40 years) **Sensory analysis** n= 8 , (5 females & 3 males), (ages 25- 40 years) **Study duration:** 3 days	**Enrichment** *Bacillus* indicus HU36, maltodextrin and lemon fiber	↑ Lemon Fiber & Maltodextrin (3.2-3.91 g/100 g) → Optimal Organoleptic Properties ↑ Maltodextrin & Lemon Fiber → ↑ Sweetness, Firmness, Adherence
Prasep-tiangga *et al.* (2019) India	untrained panelists (5-point hedonic scale)	**Addition** CBOM	no significant difference in sensory evaluation for all attributes, D1 to D3 accepted)
Koh *et al.* (2023) Malaysia	Subject: n=55, well-trained panelists , (aged 18–60 years)	**Enrichment** GABA	DC3: Most preferred (glossiness & bittersweet taste), followed by DC2 & DC1. No significant change in nutritional composition compared control.
Lagast *et al.* (2017) Belgium	Subject: n= 219 consumers	**Substitution** Tagatose and stevia	**Overall liking** DC2 ≈ DC1; DC3 ↓ significantly compared to DC1. **Sensory attributes** DC2 similar to DC1 (sweetness, bitterness, aftertaste). DC3 ↑ bitterness & aftertaste duration compared to sugar. **Emotional responses** DC2 emotional responses are similar to sugar, DC3 more negative emotions. **Consumer preferences** Older participants (46+ years) preferred DC2 less than younger groups

CB: Cocoa Butter; CBOM: Cinnamon (*Cinnamomum* burmannii) Bark Oleoresin Microcapsule; CC: Control Chocolate; DC: Dark Chocolate; GABA: Gamma-Aminobuytric Acid; MP: Microencapsulated Phytosterols; RFC: Reduced Fat Chocolate; RSM: Response Surface Methodology

of natural sweeteners, such as stevia and agave nectar, enhanced the healthfulness of the product, stevia led to a significant decrease in taste scores because of its lingering aftertaste. They also reported that agave nectar improved flavour and acceptability, whereas higher stevia levels reduced texture and mouthfeel scores. This reflects a common challenge with natural sweeteners, where health benefits may compromise the sensory appeal. Stevia's lingering aftertaste, aligns with findings in other food products, such as oatmeal cookies (Salazar *et al.* 2018), although some beverage studies suggest that partial substitution can still be acceptable (Oziyci & Karhan 2025). Recent approaches that blend different steviol glycosides have shown promise in improving sensory quality (Schiatti-Sisó *et al.* 2023).

Tolve *et al.* (2018) reported that microencapsulated phytosterols enhance smoothness and reduce grittiness without affecting sweetness or bitterness. Didar (2020) observed an improved appearance and flavour with encapsulated chlorogenic acids; however, high levels of free acids increased bitterness and reduced acceptance. These findings highlight the importance of encapsulation in minimising sensory drawbacks. Akdeniz *et al.* (2021) showed that 40% carob powder improved aroma and texture in milk chocolate, while higher concentrations decreased acceptability. Interestingly, carob-based dark chocolates performed comparably to the controls, indicating their viability. Gallegos Soto *et al.* (2020) noted that chitosan hydrogel with canola oil substitution was well-accepted, with minimal impact on sweetness and mouthfeel. Monteiro *et al.* (2023) found that 3% baobab flour enhanced texture and flavour, whereas 9% negatively affected taste and colour. Increasing the ratio of baobab pulp to dark chocolate reduced consumer acceptance,

likely due to its acidic taste. Adjusting the baobab pulp concentration to lower or moderate levels may offer a strategy to mitigate these issues while still providing functional benefits.

Ashrafie *et al.* (2014) concluded that fat-reduced chocolate with collagen hydrolysate maintained similar taste and texture scores, suggesting its potential to reduce energy content without compromising quality. Kobus-Cisowska *et al.* (2019) reported that *Bacillus coagulans*-*enriched* chocolate preserved taste and odour. This stability in sensory quality was attributed to the encapsulation process, which protected the probiotics from interacting directly with the chocolate matrix, thereby preserving the original sensory characteristics (De Prisco & Mauriello 2016). Yoriska *et al.* (2019) found that Kaffir lime essential oil reduced acceptance due to bitterness, while Handiati *et al.* (2019) observed improved aroma with Kaempferia galanga essential oil without affecting other sensory attributes.

Didar (2021) reported that vitamin D3 fortification in both free and liposomal forms did not alter key sensory parameters. Similarly, Marcial-Coba *et al.* (2019) found no effect on the sensory attributes of microencapsulated *Akkermansia muciniphila* and *Lactobacillus casei*. In contrast, Erdem *et al.* (2014) showed that maltodextrin and lemon fibres improved sweetness, firmness, and smoothness. Praseptiangga *et al.* (2019) consistently found that cinnamon bark oleoresin microcapsules (up to 8%) did not diminish sensory acceptance. Koh *et al.* (2023) noted no significant differences in sensory scores for GABA-enriched chocolate, although 0.10% was preferred for sweetness and gloss. Finally, Lagast *et al.* (2017) found that tagatose-sweetened chocolate-matched sucrose in terms of acceptability, whereas the stevia-sweetened versions were slightly bitter and less favoured.

Collectively, these findings underscore that the sensory acceptance of functional dark chocolate is highly ingredient dependent. The challenge lies in optimising concentrations, using encapsulation technologies, and carefully selecting ingredient combinations to preserve or enhance sensory quality without compromising health. Dark chocolate naturally contains bitter compounds and lacks the sweetness and creaminess of milk chocolate (Liu *et al.* 2015). This balance is particularly delicate, making thoughtful formulation essential.

Effects on beneficial health outcomes

Out of the 24 studies included in this review, seven reported significant findings on the health benefits of dark chocolate, either through its naturally occurring bioactive compounds or through fortification with additional functional ingredients, focusing primarily on cardiovascular health, metabolic regulation, and probiotic viability. Lee *et al.* (2017) investigated the effects of dark chocolate combined with almonds and reported that, although almonds alone improved lipid profiles, the combination significantly reduced small dense of Low-Density Lipoprotein (LDL) particles and apolipoprotein levels, which are considered key cardiovascular risk markers. However, no significant effects on vascular health or oxidative stress were observed.

Similarly, Rull *et al.* (2015) found no significant changes in blood pressure or heart rate following the consumption of high-flavanol dark chocolate, yet reported reduced platelet aggregation, increased endothelium-dependent vasodilation, and lower pulse pressure amplification, suggesting cardiovascular benefits. Flavonoids in cocoa, especially flavan-3-ols, are believed to inhibit cholesterol absorption and may contribute to the reduction of LDL cholesterol levels (Arisi *et al.* 2024). Therefore, the observed cardiovascular benefits could be attributed to these bioactive compounds.

Ostertag *et al.* (2017) reported that flavan-3-ol-enriched dark chocolate modulated endogenous metabolism, reducing urinary amino acids and lactate while increasing pyruvate and microbial metabolites, including theobromine derivatives. These findings suggest that the developed dark chocolate may enhance both metabolic health and microbial function. Additionally, regular consumption of cocoa polyphenols has been shown to positively influence gut microbiota composition by promoting beneficial bacteria, such as *Bifidobacterium* and *Lactobacillus*, thereby fostering a healthier gut environment that contributes to overall metabolic health (Sorrenti *et al.* 2020).

Akyol *et al.* (2014) observed that β-glucan-enriched dark chocolate led to a 20.2% reduction in subsequent energy intake despite no significant differences in hunger ratings. This result suggests that while β-glucan does not directly affect hunger, it may promote satiety, leading to reduced energy consumption in subsequent meals. These findings are promising for weight management

Table 3. Effects of DC and its functional ingredients on beneficial health effects

Author and country	Study design	Functional ingredients	Main outcomes (Health benefits)
Lee *et al.* (2017) California	**Study design:** A randomized controlled, 4-period, crossover **Subject:** n=31, overweigh/obese (age 30−70 years) **Study duration:** 4 weeks + 2-week break (washout)	**Incorporation** almonds	**Lipid Profiles Improvement** DC2 Effective in ↓ total Cholesterol, non-HDL cholesterol and large buoyant LDL particles. DC4 Effective in ↓ small dense LDL particles & apolipoprotein B (both marker of Cardiovascular risk) DC3 minimal effect on lipid profile and ↑ fasting glucose level No significant effects on Vascular Health and Oxidative stress.
Ostertag *et al.* (2017) UK	**Study design:** Randomized controlled cross-over intervention trial **Subject:** n= 42 Healthy volunteers (for urine and blood plasma samples) **Study duration:** 3 days intervention, 2 in between treatment washout periods (at least two weeks)	**Enrichment** flavan-3-ol-EDC	**Endogenous metabolism** ↓ Urinary levels of several amino acids (Ala, Val, Gly), lactate, and NMA after consumption of flavan-3-ol-EDC and standard DC. ↑ Urinary levels of pyruvate and HPA after consuming both EDC and DC. **Flavan-3-ol and methylxanthine metabolism:** ↑ Urinary markers of theobromine and its metabolites (3- and 7-methylxanthine, AMMU) post-consumption of both EDC and DC compared to WC. **Microbial metabolites** ↑ Levels of microbial metabolites (e.g., HPA) related to gut microbiota activity post-consumption of EDC and DC. **Energy metabolism** Consumption of both EDC and DC altered energy metabolism by influencing the excretion of compounds like creatinine and pyruvate. **Gender and age effects** ↑ Theobromine excretion in females compared to males and in younger participants compared to older individuals after dark chocolate consumption.
Rull *et al.* (2015) UK	**Study design:** Single centre randomized double-blind placebo-controlled investigation with a crossover **Subject:** n= 32 (aged 45−70 years) **Study duration:** 6 weeks	**Enrichment** HF	**Blood pressure & heart rate** ↓**SBP:** HFDC tended to lower SBP by ~2 mmHg compared to LFDC, but the effect was not statistically significant. ↑ **Heart rate with LFDC:** LFDC increased heart rate by ~4 bpm, while HFDC had no significant effect on heart rate. **Vascular function** ↑ **Endothelium-dependent vasodilation:** HFDC tended to improve vascular responses to salbutamol, though the effect was modest and did not reach statistical significance. ↓ **PPA:** HFDC reduced PPA compared to LFDC, indicating a potential benefit for cardiovascular function. **Platelet aggregation** ↓ Platelet Aggregation with HFDC & LFDC: Both HFDC and LFDC significantly reduced platelet aggregation induced by ADP and TRAP6, likely due to theobromine, a PDE inhibitor present in both chocolates. **No effect on collagen-induced aggregation** **Lipid profile** **No significant changes:** There were no significant changes in total cholesterol, LDL, HDL, or triglycerides after consumption of HFDC or LFDC.
Akyol *et al.* (2014) Turkey	**Study design:** single blind, randomized, crossover design **Subject:** n=25 Healthy subjects Female subjects from Hacettepe University (ages 19–25 Years) **Study duration:** 4 days	**Incorporating** β-Glucan	↑ DC→ ↓ Energy Intake (20%) ↑ β-Glucan → No Significant Effect on Satiety compared to **DC3** DC+ β-Glucan → No Additional Impact on Energy Intake no significant differences in hunger, satiety, or prospective food consumption

Continue from Table 3

Author and country	Study design	Functional ingredients	Main outcomes (Health benefits)
Wiese *et al.* (2019) UK	**Study design:** Randomized, double blind, intervention trial **Subject:** n=30 (15 male, 15 female) moderately obese with BMI between 30 and 35 kg/m2 (ages 40–68 Years) **Study duration:** 1 month	**Fortification** Lycopene	**Gut microbiota** ↑ Lycopene → ↑ *Bifidobacterium* adolescents & Bifidobacterium longum ↑ DC → ↑ *Lactobacillus* **Liver and blood markers:** Lycopene (7 mg dose): ↓ IOD by 35%, ↓ LDL-Px by 36%. Lycopene (30 mg dose): ↓ IOD by 60%, ↓ LDL-Px by 43%. DC: ↓ IOD by 35%, less effective for ↓ LDL-Px compared to lycopene. **Skeletal muscles and oxygenation** Lycopene (30 mg dose): ↑ Tissue oxygenation (25% improvement with liver-targeting formulation). DC: No significant improvement in tissue oxygenation. **Skin health** Lycopene: ↓ Corneocyte exfoliation rate by 23%, ↓ bacterial load on skin surface. DC: Minimal changes in skin parameters.
Marcial-Coba *et al.* (2019) Denmark	**Study design:** In vitro experimental study Storage study lasted for 60 days (15,30 & 60 d)	**Fortification** Akkermansia *muciniphila* and *Lactobacillus casei.*	**DC1**→ 0.63 log CFU reduction at 4°C, 0.87 log CFU reduction at 15°C after 60 days **DC2**→ No significant viability loss during 60 days at 4°C and 15°C ↑ Microencapsulation in xanthan/gellan gum → ↑ Survival of *A. muciniphila* & *L. casei* during in vitro gastric transit (pH 3) ↑ Chocolate matrix → 1.80 log CFU improvement in survival for *A. muciniphila*, 0.8 log CFU for *L. casei* during gastric transit compared to free cells
Felice *et al.* (2019) Italy	**Study design:** Randomized, single-blind, crossover trial **Subjects:** n= 30 (14 male, 12 female) with CVD risk factors **Study duration:** 4 weeks/treatment + 2-week washout	**Enrichment** EVOO Panaia Red Apples	**EVOO-enriched DC:** ↑ Circulating EPCs=Better cardiovascular repair and endothelial function. ↓ Oxidative stress (due to EVOO's rich antioxidants). **Apple-enriched DC** ↔ No significant change in EPCs. ↑ Slight increase in LDL, but not significant. **Other health markers** ↔ No significant effect on glucose, total cholesterol, HDL, or blood pressure in either group.

ADP: Adenosine Diphosphate; BMI: Body Mass Index; CFU: Colony Forming Unit; DC: Dark Chocolate; EDC: Enriched Dark Chocolate; EPC: Endothelial Progenitor Cells; EVOO: Extra Virgin Olive Oil; HDL: High-Density Lipoprotein; HFDC: High Flavanol Dark Chocolate; HPA: Para-Hydroxyphenylacetate; IOD: Inflammatory Oxidative Damage; LDL: Low-Density Lipoprotein; LFDC: Low Flavanol Dark Chocolate; NMA: N1-methylnicotinamide; PPA: Pulse Pressure Amplification; SBP: Systolic Blood Pressure

strategies, as they indicate that β-glucan can be a valuable additive to dark chocolate, potentially offering benefits for appetite regulation and reducing overeating. However, further research is necessary to elucidate its role in appetite regulation given the lack of significant changes in hunger and prospective food consumption.

Felice *et al.* (2019) showed that Extra Virgin Olive Oil (EVOO)-enriched dark chocolate increased Endothelial Progenitor Cells (EPCs), indicating improved vascular repair, whereas apple-enriched chocolate had no effect on the EPCs. Marcial-Coba *et al.* (2019) found that chocolate fortified with microencapsulated *Akkermansia muciniphila* and *Lactobacillus casei* enhanced probiotic survival during gastric transit, particularly when stabilised with xanthan and gellan gum. Lastly, Wiese *et al.* (2019) demonstrated that lycopene-enriched chocolate improved gut microbiota composition, reduced oxidative damage, enhanced tissue oxygenation, and improved skin health, whereas plain dark chocolate showed only minor benefits.

This scoping review identifies several shortcomings but also underscores the potential of dark chocolate as a functional food with notable

health benefits and enhanced physicochemical properties. These findings suggest that dark chocolate can be further optimised in terms of its physicochemical properties and product formulation for broader consumer acceptance. Advancements in ingredient formulation and processing techniques since 2013 have demonstrated a growing awareness of both nutritional value and sensory quality. However, further research is needed to fully understand the long-term health effects and refine formulations that appeal to a wider range of consumers. Future research should also focus on standardised methodologies for both physicochemical and sensory evaluations to enable more consistent comparisons between studies.

Gaps and opportunities

Despite these promising findings, several gaps and opportunities were identified across the 24 studies reviewed, suggesting key areas for future research. First, while many studies have focused on short-term interventions, there is a notable lack of long-term clinical trials examining the sustained health benefits of dark chocolates enriched with functional ingredients. For example, studies on cardiovascular health, such as that by Lee *et al.* (2017), were limited to only a few weeks, leaving questions about the longevity of the observed benefits. Additionally, balancing health benefits with sensory acceptance remains a challenge, where the introduction of Kaffir lime essential oil resulted in an overpowering aftertaste for some participants, suggesting that further optimisation is needed (Yoriska *et al.* 2019).

The study by Nurhayati *et al.* (2022) offers valuable insights into the use of coconut and palm sugars in chocolate formulations; however, several gaps and opportunities for further research remain. This study demonstrates the functional potential of palm sugar in managing blood glucose levels, but long-term clinical trials to validate its sustained health benefits are lacking. Additionally, although antioxidant activity was measured, the study did not explore the impact of these functional ingredients on human health outcomes. Future research should also investigate the sensory properties and consumer acceptance of these sugar alternatives in chocolates, as well as their broader applicability in other food products. Moreover, several studies lack a comprehensive analysis of the physicochemical changes over storage time, particularly regarding ingredient stability and interactions with the chocolate matrix. Lastly, while many studies emphasise the potential health-promoting properties of dark chocolates with functional ingredients, limited attention has been given to understanding their bioavailability and how various processing methods may affect the efficacy of bioactive compounds, creating opportunities for future research in this area.

CONCLUSION

This scoping review highlights that from 2013 to 2024, numerous studies have demonstrated the potential of dark chocolate enriched with functional ingredients to enhance physicochemical properties, sensory acceptance, and health benefits. Most formulations retained or improved chocolate's core qualities, particularly when incorporating polyphenol-rich compounds (e.g., cocoa flavanols, carob powder, green coffee extract) and natural sweeteners (e.g., stevia, agave nectar, coconut sugar). Microencapsulation emerged as an effective strategy to improve ingredient stability, mask off-flavours, and maintain sensory appeal. Functional additions such as probiotics, prebiotic fibres, and essential oils not only enriched nutritional profiles but also contributed to better gut health, product texture, and shelf-life.

Despite promising results, further long-term research is needed to explore the bioavailability and health impacts of these bioactive compounds, especially in relation to cardiovascular health, gut microbiota, and metabolic disorders. Sensory preferences across diverse populations also warrant deeper investigation to ensure product acceptance. Future studies should prioritise optimising formulation techniques that balance health functionality with consumer appeal, thereby supporting the development of dark chocolate as a palatable and effective functional food. These recommendations will strengthen research in this area, foster more robust evidence, and enable better cross-study comparisons.

RECOMMENDATIONS

Consequently, additional research focusing on observational studies is necessary to obtain clearer conclusions supported by epidemiological data. Considering the limited number of published cohort studies, further investigation is essential to

strengthen the findings presented in this scoping review.

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DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest.

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