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DAIRY PROTEIN FORTIFICATION IN CONFECTIONERY: NUTRITIONAL SIGNIFICANCE, FUNCTIONAL BEHAVIOR, AND QUALITY EFFECTS

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ABSTRACT
Confectionery products such as chocolate, caramel, toffee, and nougat are widely consumed, but they are usually low in protein. Adding dairy proteins offers a practical route to improve their protein contribution, yet the same ingredients that raise protein content can alter flow, texture, melting, color, and flavor. This review examines the nutritional and functional roles of whey protein concentrate, whey protein isolate, milk protein concentrate, micellar casein, and casein-rich ingredients in protein-enriched confectionery, with emphasis on evidence from chocolate and frozen desserts. Milk proteins provide all indispensable amino acids and are digestible, but the nutritional value of a fortified product depends on the ingredient composition, the amount added, processing, and the final serving size. Direct product studies show that whey protein ingredients can increase viscosity and yield stress, modify hardness and fracture behavior, change melting profiles, and influence surface bloom, although the direction and magnitude of these effects are formulation-specific. In milk chocolate, 6% whey protein concentrate or its hydrolysate increased apparent viscosity without major sensory changes, whereas high-protein white and dark chocolates containing whey protein isolate and erythritol developed firmer structures and greater melting resistance. Evidence for caramel, toffee, and nougat remains limited. The review identifies the need for controlled comparisons of protein types, complete formulation reporting, integrated sensory and storage testing, and pilot-scale validation. Dairy protein fortification is feasible, but it should be treated as a reformulation step whose nutritional benefit must be demonstrated in the finished product rather than assumed from ingredient composition.

Keywords: dairy proteins; whey protein; chocolate; confectionery; texture; rheology

INTRODUCTION
Confectionery products such as chocolate, caramel, and toffee are valued for their characteristic sweetness, flavor, appearance, and texture. Even modest changes in ingredients or processing can alter these qualities. In chocolate, particle composition and distribution within the cocoa-butter phase influence flow during manufacture as well as texture and melting during consumption (Gunes *et al*., 2022; Toker *et al*., 2023; Lipkin *et al*., 2025). Protein enrichment offers an opportunity to improve the protein contribution of familiar confectionery products, but the added ingredient must be selected carefully so that nutritional improvement does not come at the expense of product quality. Dairy proteins are useful ingredients because milk contains casein and whey fractions with high nutritional value and established functional properties, including emulsification, gel formation, and water binding (Auestad and Layman, 2021; Yiğit *et al*., 2023; Nayik *et al*., 2024). Their performance depends on ingredient composition, processing, and interactions with other components; heating, drying, and storage may also promote protein denaturation or aggregation and affect solubility (Kong *et al*., 2022; Finnegan *et al*., 2024; Hu *et al*., 2024). The dairy ingredients used for fortification include whey protein concentrate (WPC), whey protein isolate (WPI), milk protein concentrate (MPC), micellar casein, and milk powders. These ingredients differ in protein concentration and in the amounts of lactose, minerals, and fat present, while processing influences their functional characteristics and digestibility (Carter *et al*., 2021; Fitzpatrick *et al*., 2024). Ingredient type and final formulation therefore need to be reported clearly when results from different studies are compared.
Most direct research on dairy-protein enrichment in confectionery has focused on chocolate. Studies have shown that WPC and hydrolyzed WPC can change milk-chocolate rheology (Rakin *et al*., 2023), while WPI-based dark and white chocolate formulations can show changes in mechanical, surface, melting, and microstructural properties (Nastaj *et al*., 2022, 2024). These effects are formulation-specific because the protein ingredient, sweetener, fat phase, and processing conditions all contribute to the final structure. Chocolate research also demonstrates the importance of particle characteristics, conching, and fat crystallization in determining flow and surface quality (Feichtinger *et al*., 2020; González *et al*., 2021, 2022; Konar *et al*., 2024). Protein addition to caramel, toffee, and other cooked sugar confectionery presents additional challenges because concentrated sugars, moisture, acidity, and heating conditions influence color, flavor, and texture. Reactions between proteins and reducing sugars may contribute to desirable flavor and color, but can also affect amino-acid availability and generate unwanted

compounds (Xiang *et al*., 2021; Poojary and Lund, 2022; Li *et al*., 2022). Sensory acceptance and storage stability must therefore be assessed alongside instrumental measurements, since changes in viscosity, hardness, or melting behavior alone do not establish consumer preference or shelf life (Watanabe *et al*., 2021; McKenzie and Lee, 2022; Konar *et al*., 2024). Although current studies provide useful evidence for selected chocolate formulations, findings cannot be transferred directly to caramel, toffee, or nougat, where the composition and thermal history differ. This review examines the nutritional and functional roles of dairy ingredients in protein-enriched confectionery, their effects on physicochemical and sensory properties, and the research needed to develop products that provide additional protein while retaining the qualities expected by consumers (Gunes *et al*., 2022; Lipkin *et al*., 2025).

METHODOLOGY

This review was prepared as a narrative synthesis of published research on dairy-protein fortification of confectionery. Literature was identified through targeted searches of Scopus, Web of Science, and Google Scholar using combinations of the terms "dairy protein," "whey protein," "milk protein concentrate," "casein," "chocolate," "caramel," "toffee," "nougat," "confectionery," "rheology," "texture," "melting," and "sensory." Additional records were identified by checking the reference lists of relevant reviews and primary studies and by citation tracking of key papers. Studies were eligible if they were peer-reviewed publications that reported the use of a dairy-protein ingredient in a confectionery or frozen-dessert formulation, or that provided directly relevant evidence on dairy-protein composition, digestion, functionality, or physicochemical behavior. Priority was given to studies that described the protein ingredient and addition level, a control formulation, processing conditions, and at least one product-quality measurement. Conference abstracts, patents, theses, and reports lacking sufficient formulation or outcome detail were excluded. Only English-language publications were considered. Records were screened by title and abstract, and potentially relevant full texts were assessed against these criteria. The review was narrative rather than systematic; no formal risk-of-bias assessment or PRISMA flow diagram was used. The evidence was synthesized qualitatively and organized into five themes: dairy-ingredient characteristics, nutritional significance, product-specific evidence, functional roles, and physicochemical effects. Differences in formulation, processing, and test methods were considered when comparing studies, and quantitative values were reported only when they could be verified from the original publications.

RESULTS AND DISCUSSION

DAIRY INGREDIENTS USED FOR PROTEIN ENRICHMENT

Dairy proteins used for food fortification are supplied in several ingredient forms, including WPC, WPI, MPC, milk protein isolate (MPI), caseinates, and micellar casein concentrate (MCC). These materials differ in their casein-to-whey ratio and in the amounts of lactose, minerals, and other solids retained during manufacture; therefore, the ingredient name and its specification are important when comparing formulations (Hammam *et al*., 2021; Liu *et al*., 2024). MPC powders, for example, are produced by concentrating milk proteins and retaining both casein and whey proteins, while the final powder characteristics are influenced by the concentration and drying steps (Meena *et al*., 2021). The distinction between whey-rich and casein-rich ingredients is relevant to their performance in a confectionery matrix. Whey proteins can interact with other food components, including polysaccharides, polyphenols, and other proteins, through non-covalent interactions that may alter the structure and functionality of the combined system (Kong *et al*., 2022). Caseins also have multiple binding sites and can associate with different food-derived compounds, which has supported their study as carriers for selected ingredients in food systems (Casanova *et al*., 2021). These findings do not mean that every interaction will improve a confectionery product; rather, they show why the behavior of a dairy protein should be considered alongside the other ingredients in the recipe (Liu *et al*., 2024).

For MPC and MCC, hydration and solubility are practical considerations. Poor solubility of MPC can develop through changes in powder structure and interactions between casein and whey proteins during manufacture or storage; these changes may limit the functional performance of the ingredient in food processing (Khalesi and FitzGerald, 2022). Research comparing high-protein dairy powders has also shown that powder composition and microstructure are related to handling and reconstitution behavior, and that different powders do not behave identically when mixed with water (Salunke *et al*., 2023). The protein ratio, standardizing solution, and heat-treatment conditions can influence particle properties and changes during storage, so these factors should be taken into account when choosing an ingredient for a new formulation (Lee *et al*., 2023). Rehydration is especially important when a dry dairy ingredient must disperse evenly before it is incorporated into a food mixture. Roy and Amamcharla (2025) noted that high-protein dairy powders, particularly casein-rich MPC and MCC, can show slow rehydration, poor wettability, or residual insoluble particles. In product development, incomplete dispersion may lead to uneven distribution and processing difficulties; a suitable hydration method and controlled mixing conditions are therefore part of ingredient selection rather than minor preparation details (Khalesi and FitzGerald, 2022; Roy and Amamcharla, 2025). For studies intended to be compared across laboratories, it is useful to report the ingredient grade, protein content, pre-hydration conditions, and the way the powder is added to the confectionery mix (Salunke *et al*., 2023; Lee *et al*., 2023).

Chocolate illustrates how the form of a dairy-derived ingredient can matter in addition to its nutritional contribution. In a recent study, engineered whey-protein particles were used to structure oil, and the resulting oleogel was tested as a partial cocoa-butter replacement in chocolate; the formulations differed in hardness, melting response, and lubrication under simulated oral conditions (Zhou *et al*., 2026). This work is not a direct comparison

of WPC, WPI, and MPC as protein fortifiers, but it demonstrates that the structural design of whey-protein ingredients can influence the physical properties of a chocolate system. Processing history also matters because emerging thermal and nonthermal treatments can modify whey-protein functionality and digestibility; the ingredient specification should therefore include the treatment applied (Kheto *et al*., 2025). Overall, dairy ingredient selection should be based on the target protein level together with dispersibility, compatibility with fat and sugar, processing behavior, and the quality attributes expected in the finished confectionery (Hammam *et al*., 2021; Liu *et al*., 2024).

NUTRITIONAL SIGNIFICANCE OF DAIRY PROTEIN FORTIFICATION

The nutritional value of a protein-enriched confectionery product depends on what the added protein contributes to the final food, not simply on the amount of powder used in the recipe. Protein supplies amino acids required for tissue maintenance, enzyme production, and many other physiological functions. To assess its quality, both the indispensable amino acid pattern and the digestibility of those amino acids need to be considered; a high protein value on a label does not describe these features by itself (Adhikari *et al*., 2022; Calvez *et al*., 2024). Milk proteins are commonly used for fortification because they provide all nine indispensable amino acids and are generally regarded as high-quality protein sources (Auestad and Layman, 2021; Karoui and Bouaicha, 2024). Casein and whey, the two main protein fractions in milk, do not behave identically during digestion. Casein tends to coagulate in the stomach, so its emptying and the release of amino acids are generally slower than those of whey protein. Whey is usually digested more rapidly, although the response also depends on processing and the food in which the protein is eaten (Horstman and Huppertz, 2023). This difference matters when selecting a dairy ingredient, but it should not be overstated: a confectionery study cannot establish a physiological benefit merely by showing that whey or casein has been added. Such a claim would require relevant nutritional or human evidence.

Milk proteins and peptides have also been investigated for biological activities beyond their role as amino acid sources. Some peptides released from dairy proteins during digestion or processing have shown activities in experimental research, including mineral binding and other potential effects (Auestad and Layman, 2021). These findings are scientifically interesting, but they should be described cautiously. The presence of a potentially active peptide does not mean that the same effect will occur after eating a protein-enriched chocolate or toffee, because the amount released, its stability during digestion, and its availability in the body all matter. For product development, the most direct nutritional outcome to establish first is the actual protein content of the finished product. The composition of the dairy ingredient also affects the final nutritional profile. WPC, WPI, milk protein concentrates, and casein-rich ingredients differ in the amounts of protein, lactose, minerals, and fat they contain. Consequently, two recipes with the same quantity of added powder may not provide the same amount of protein or the same energy value. Processing adds another layer of variation: heating and other treatments may change protein structure and its subsequent digestion, so the properties of the raw ingredient should not automatically be treated as identical to those of the processed food (Fitzpatrick *et al*., 2024). The wider food matrix matters too; the way nutrients are organized and interact within a food can influence its physical properties and nutritional response (Huppertz *et al*., 2024).

Studies on protein-enriched chocolate show both the potential and the practical limits of this approach. High-protein dark and white chocolates have been produced with WPI and erythritol (Nastaj *et al*., 2022, 2024), and milk chocolate has been fortified with WPC or hydrolyzed WPC (Rakin *et al*., 2023). These formulations demonstrate that protein enrichment is technically feasible, but they also show that changing the protein level affects the product itself, not just its nutritional composition. The magnitude of the change depends on the ingredient and the surrounding recipe. A protein claim should also be interpreted in the context of the whole product. Confectionery can provide additional protein, but sugar content, fat, energy density, and normal serving size remain relevant when its nutritional profile is assessed. Research on the dairy matrix cautions against judging foods only as a list of individual nutrients because the structure of the food and interactions among its components also matter (Huppertz *et al*., 2024). Therefore, a protein-enriched confectionery should not automatically be described as a healthy or balanced food simply because its protein content is higher. Any comparative nutritional statement should be based on the composition of the finished product and, where relevant, the amount consumed (Drewnowski, 2025).

For this reason, nutritional assessment should include the protein content of the finished confectionery and report it alongside serving size, sugar, fat, and energy. Where feasible, amino acid composition or an accepted protein-quality measure can provide a more informative picture than crude protein alone; digestibility evidence is useful when the effect of processing is part of the research question (Adhikari *et al*., 2022; Calvez *et al*., 2024; Fitzpatrick *et al*., 2024). Studies should also state the type and level of dairy ingredient used so that results can be compared fairly. Overall, dairy protein fortification offers a practical way to increase protein in chocolate and related products, but its nutritional value should be demonstrated in the final formulation and considered alongside sensory acceptability and processing performance (Rakin *et al*., 2023).

PROTEIN-ENRICHED CONFECTIONERY PRODUCTS

Protein-enriched confectionery is being explored as a way of increasing protein intake through familiar products rather than creating a completely new food format. The work published so far is concentrated mainly on chocolate and frozen desserts, where dairy proteins can be incorporated into formulations and their effects can be measured against a conventional control (Nastaj *et al*., 2022, 2024; Kiełczewska *et al*., 2025). The studies are useful examples, but they also show that adding protein changes the physical system: the protein ingredient may affect flow, texture, melting behavior, microstructure, and, in some cases, sensory quality (Rakin *et al*., 2023; VanWees

et al., 2026). Chocolate has received particular attention because it is a dense suspension of sugar, cocoa, and milk-derived particles in a fat phase. Replacing part of the usual ingredients or adding a protein powder changes the composition and the way the particles pack together; the consequence may be a different viscosity or mechanical response, even when the finished product retains a recognizable chocolate character (Nastaj *et al*., 2022; Rakin *et al*., 2023). Flow behavior is also temperature-dependent, which matters during pumping, tempering, and deposition (Kumbár *et al*., 2021). For this reason, protein content should be considered together with the processing requirements of the product. A formulation that looks promising nutritionally may still be difficult to deposit or mold if its flow behavior changes too much.

Rakin *et al*. (2023) compared standard milk chocolate with samples containing 6% WPC or 6% trypsin-hydrolyzed WPC. The reported mean viscosity increased from 3.53 Pa·s in the control to 9.17 Pa·s with WPC and 11.81 Pa·s with hydrolyzed WPC (Figure 1). The authors reported that the extra ingredients did not significantly change hardness or enthalpy, and major sensory changes were not observed, although the hydrolyzed protein produced the larger increase in viscosity (Rakin *et al*., 2023). These findings suggest that the nature of the protein ingredient matters: hydrolysis can change its interaction with the chocolate matrix, so formulations need to be checked individually rather than assuming that the two whey ingredients will behave alike.

[Figure 1]

A second line of work has focused on high-protein, sugar-free dark chocolate. Nastaj *et al*. (2022) prepared formulations with 16%, 20%, and 24% protein using WPI and erythritol. Higher WPI additions affected the surface and microstructure of the chocolate and improved mechanical properties and resistance to melting in the tested formulations. The study also reported an anti-blooming effect, which was relevant because the products were made without conventional tempering. These results are formulation-specific and should not be read as proof that increasing WPI will improve every chocolate recipe (Nastaj *et al*., 2022).

The approach was later examined in white chocolate, with protein levels of 12%, 16%, 20%, and 24% (w/w) in formulations containing WPI and erythritol (Nastaj *et al*., 2024). Increasing the WPI level was associated with changes in viscosity, yield stress, hardness, surface properties, and resistance to melting. The authors described a denser three-dimensional network at higher protein levels and reported an anti-blooming effect relative to the reference chocolate (Nastaj *et al*., 2024). Because dark and white chocolate differ in their ingredients, findings from one type should not be directly transferred to the other without testing. Protein fortification has also been studied in frozen desserts. Kiełczewska *et al*. (2025) compared ice cream made with MCC, buttermilk protein concentrate, and WPC80 against a skim-milk-powder control. Protein enrichment increased the protein content of the mixes, but the preparations did not have identical effects on consistency, hardness, overrun, or melting rate. The WPC-containing ice cream had the highest reported hardness (276.54 N), the lowest overrun (52.40%), and the highest melting rate (0.24 g/min) among the tested preparations; sensory scores were also lower for the WPC formulation for attributes including fluffiness and sour aroma or taste (Kiełczewska *et al*., 2025). That trade-off shows why product development should evaluate the finished dessert, not only the nutrition panel.

Research on high-protein frozen desserts further shows that the type of dairy protein changes how the mix forms its structure during freezing. VanWees *et al*. (2026) studied formulations containing 6% MPC, sodium caseinate, or WPI and reported that protein structure influenced the ice, air, and fat phases and the resistance of the product to collapse during melting. A recent review also identifies formulation performance, texture, and sensory quality as central challenges in incorporating protein supplements into ice cream (Mykhalevych *et al*., 2026). Although ice cream is not identical to a cooked sugar confection, these studies are relevant because they demonstrate a consistent principle: the effect of protein depends on the surrounding food matrix and the other ingredients. Across the studies, the most defensible conclusion is not that protein enrichment invariably improves confectionery, but that it can be achieved when the formulation is designed around the specific ingredient and product type (Table 1). A meaningful comparison should report the type and amount of protein added, the reference formulation, the protein content of the finished product, processing conditions, instrumental properties, and sensory results. The published work is currently more developed for chocolate and frozen desserts than for protein-enriched caramel, toffee, and nougat. More studies on those cooked sugar products are needed before conclusions drawn from chocolate can be generalized to them (Nastaj *et al*., 2022, 2024; Kiełczewska *et al*., 2025; Mykhalevych *et al*., 2026).

[Table 1]

FUNCTIONAL ROLE OF DAIRY PROTEINS IN CONFECTIONERY SYSTEMS

Dairy proteins do more than raise the protein content of confectionery. Depending on their structure and the conditions used during manufacture, they can influence the way ingredients disperse, how a product flows before setting, and the texture and stability of the finished item. Casein and whey proteins differ in molecular organization and their response to heat; those differences underpin properties such as emulsification, gelation, water interaction, and the formation of protein networks (Nayik *et al*., 2024; Rodrigues *et al*., 2026). Interactions between dairy and plant proteins can further modify emulsifying and gelling behavior in mixed systems (Rout *et al*., 2024). However, these general functions should not be treated as interchangeable effects in every confectionery. Chocolate, for example, is mainly a particle suspension in a continuous fat phase, whereas many cream fillings and chewy confections contain more water. The functional role expressed by a protein therefore depends on the product matrix, rather than on the protein ingredient alone (Figure 2).

[Figure 2]

One of the clearest demonstrations in confectionery is the effect of whey protein on chocolate rheology. As described above, Rakin *et al*. (2023) found that 6% WPC and 6% trypsin-hydrolyzed WPC raised the apparent viscosity of milk chocolate above that of the control. The hydrolyzed ingredient produced the highest viscosity under the tested conditions. A higher viscosity may help some formulations maintain body, but it can also raise resistance during pumping, depositing, or mold filling. It is therefore not inherently an improvement. Rakin *et al*. (2023) also reported that the additions did not significantly affect hardness or enthalpy, and no major change in the sensory characteristics was observed. Taken together, their results show that a strong change in a flow measurement does not necessarily produce a matching change in bite or perceived flavor. The use of hydrolyzed WPC may be useful where a thicker chocolate mass is acceptable, but the process settings would need to be checked rather than carried over from the control recipe. Dairy proteins can also contribute to structure formation. Whey proteins undergo unfolding and aggregation during heating, while the behavior of casein micelles is shaped by pH, mineral balance, and processing intensity. These transitions may be used to develop a network or may become a source of instability if processing is too severe (Rodrigues *et al*., 2026). In aqueous confectionery fillings, soft caramels, or protein-containing gels, this structural role can affect firmness and water retention. In low-moisture chocolate, however, the same description must be used more carefully: rheology and texture are strongly influenced by the packing and interaction of solid particles within the fat phase. The relevant question is not whether dairy proteins can form gels in general, but whether the conditions in a particular confectionery allow that function to develop.

Surface properties and melting behavior are another relevant function in chocolate. Nastaj *et al*. (2022) reported that WPI, together with erythritol, changed the microstructure and mechanical behavior of high-protein, sugar-free dark chocolate and improved its resistance to melting under the conditions tested. In a later study of white chocolate, higher WPI levels were associated with a denser three-dimensional solid network, higher mechanical responses, and improved melting stability; the formulations also showed an anti-blooming effect (Nastaj *et al*., 2024). These observations are consistent with the idea that proteins can alter how the solid phase is organized. Nevertheless, the effect should be attributed to the whole formulation-WPI, sweetener, fat, and processing-not to protein alone, because the studies changed several ingredients together. These thermal effects are examined in more detail below. At interfaces, casein and whey proteins can adsorb and interact with other food components. The amphiphilic structure of casein supports emulsifying behavior, while whey proteins can form non-covalent associations with proteins, polysaccharides, and polyphenols; the consequences depend on pH, temperature, concentration, and the properties of the partner ingredient (Kong *et al*., 2022; Nayik *et al*., 2024). This is relevant to chocolate fillings, praline centers, and confectionery systems containing fat and water phases. Yet an interfacial benefit demonstrated in a model emulsion cannot automatically be claimed for a chocolate bar, whose continuous fat phase and high solid content create a different physical structure. Product-level testing remains necessary.

From a formulation perspective, the useful functional target should be defined before a protein ingredient is selected. If the goal is to maintain a smooth, pumpable chocolate mass, viscosity and yield stress are key responses. If the product is a filling, emulsion stability and water management may be more important; for a molded bar, fracture, surface appearance, bloom, and melting behavior may dominate. In each case, protein type, degree of hydrolysis, inclusion level, moisture, fat phase, sweetener, and thermal history should be reported alongside the measured response. Sensory results should then be considered with the instrumental data, since an apparent improvement in one property may be accompanied by a processing trade-off (Rakin *et al*., 2023). Table 2 separates direct confectionery evidence from broader mechanistic knowledge because this distinction matters when interpreting the literature. The strongest direct data currently cited here concern chocolate rheology, mechanical properties, melting behavior, and surface stability. Claims about emulsification or water binding are supported by dairy-protein functionality research, but evidence in specific confectionery systems is less developed. A rigorous review should not present these two evidence levels as equivalent.

[Table 2]

Overall, dairy proteins act as formulation tools rather than universal quality enhancers. Their contribution may involve nutrient enrichment, flow control, network development, or matrix stabilization, but the effect is conditional on the surrounding ingredients and processing conditions. Direct confectionery studies remain concentrated on chocolate, leaving a need for controlled investigations in caramel, toffee, nougat, and other sugar-based products. Comparative work should report enough formulation and processing detail to allow researchers to distinguish the effect of protein type from that of sweeteners, fat replacement, and tempering conditions (Kong *et al*., 2022; Nayik *et al*., 2024; Rodrigues *et al*., 2026).

EFFECT ON PHYSICOCHEMICAL PROPERTIES

Dairy-protein fortification can alter the flow, texture, surface properties, and stability of confectionery. The direction and magnitude of the change depend on the protein ingredient, its level, and the other formulation and processing variables. This is particularly clear in chocolate, where proteins and other solids interact within a fat-rich matrix; a change in one measured property does not necessarily produce a matching change in another (Rakin *et al*., 2023; Lipkin *et al*., 2025).

Rheology and Texture

A useful example comes from Nastaj *et al*. (2024), who prepared untempered white chocolates with WPI and erythritol at final protein levels of 12%, 16%, 20%, and 24%. At a shear rate of 10 s^{-1}, the sample containing 24% protein had the highest reported viscosity (10.10 Pa·s), compared with 1.23 Pa·s for the sucrose control and 1.69 Pa·s for the erythritol control. The reported yield stress also rose from 2.94 Pa in the sucrose control and 3.54 Pa

in the erythritol control to 84.69 Pa in the 24% protein formulation (Nastaj *et al*., 2024) (Figure 3). These changes are relevant to processing because viscosity and yield stress influence how easily a chocolate mass flows, is deposited, and fills molds.

[Figure 3]

Texture measurements followed a similar trend. Hardness increased from 65.42 N in the sucrose control to 130.36 N in the 24% protein formulation, while force at fracture rose from 62.70 to 126.04 N (Nastaj *et al*., 2024) (Figure 4). These results suggest that the higher-protein formulations formed a firmer structure under the test conditions. However, the recipe also changed the erythritol level as WPI increased, so the response cannot be assigned to protein alone. The study is best interpreted as evidence for the behavior of the complete WPI–erythritol formulation.

[Figure 4]

Water activity decreased across the same series, from 0.321 in the sucrose control and 0.318 in the erythritol control to 0.263 in the 24% protein formulation (Nastaj *et al*., 2024) (Figure 5). Lower water activity can be relevant to product stability, but it should not be used alone to claim a longer shelf life: packaging, storage temperature, fat changes, sensory quality, and microbiological criteria also need consideration. The authors reported improved melting resistance and changes in surface and microstructural properties as WPI increased, while color parameters were affected to a smaller extent (Nastaj *et al*., 2024).

[Figure 5]

Rakin *et al*. (2023) observed a different balance of effects in milk chocolate. Although 6% WPC and 6% trypsin-hydrolyzed WPC raised apparent viscosity, hardness and enthalpy did not change significantly under the conditions tested, and the sensory profile remained broadly acceptable. Taken together, the studies show that protein enrichment can substantially affect rheology and structure, but these effects are formulation-specific. Future comparisons should report protein grade, sweetener and fat composition, processing conditions, measurement temperature, and replicate variability; results from chocolate should not automatically be generalized to caramel, toffee, or nougat.

Antioxidant Capacity and Polyphenol Content

Rakin *et al*. (2023) also reported total polyphenol content and radical-scavenging capacity for the control and hydrolyzed-WPC milk chocolates. Total polyphenols increased from 877.1 ± 56.0 to 1007.8 ± 96.8 mg gallic acid equivalents per 100 g, while ABTS [2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)] inhibition rose from 48.46 ± 2.11% to 66.30 ± 1.99% and DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition from 48.07 ± 2.80% to 56.34 ± 3.20% (Figures 6 and 7). The direction of these changes is consistent with the contribution of cocoa-derived polyphenols and with the possibility that hydrolysis released additional antioxidant peptides, but the measurements do not identify which compounds were responsible.

[Figure 6]

[Figure 7]

These results should be interpreted as in vitro assay outcomes, not as evidence of a health effect in consumers. Radical-scavenging assays measure the capacity of a sample extract to react with a specific radical under laboratory conditions; they do not account for digestion, absorption, metabolism, or the amount of product normally eaten. A chocolate containing more polyphenols or showing higher ABTS or DPPH inhibition is not therefore a functional food by default. The antioxidant data are useful for product characterization and for generating hypotheses, but any health claim would require bioavailability and human studies, together with a clear statement of the serving size and the background diet.

Thermal and Melting Behavior

Thermal behavior is an important quality attribute in confectionery because it influences product firmness during handling and the way the product softens or melts during consumption. In chocolate, melting is governed largely by the fat phase, particularly the crystal structure of cocoa butter. The desired crystal arrangement contributes to snap, gloss, and a melting profile close to mouth temperature; changes in formulation or processing may disturb this balance (Lipkin *et al*., 2025). Dairy ingredients may influence the thermal behavior of chocolate through their protein, lactose, and fat fractions, as well as through their interaction with the cocoa-butter phase. Lapčíková *et al*. (2022) examined milk chocolate in which whey powder was added at 0, 2.5, 5.0, 7.5, and 10% by replacing part of the skim milk powder. Differential scanning calorimetry (DSC) was used to determine the onset, peak, and endset temperatures of melting. The peak temperature declined from 34.10 °C in the control to 32.93 °C at 10% whey powder, while the endset temperature decreased from 38.61 °C to 34.85 °C. The onset temperature did not follow a linear trend: it increased at 2.5% whey powder and then remained close to 29.5 °C at higher inclusion levels (Lapčíková *et al*., 2022) (Figure 8).

[Figure 8]

The lower peak and endset temperatures indicate that the melting transition shifted as whey powder replaced part of the skim milk powder. The authors also observed a change in cocoa-fat crystal structure and a faster melting response at higher whey-powder levels (Lapčíková *et al*., 2022). This effect should be interpreted as a response of the complete chocolate formulation rather than as the melting behavior of whey protein in isolation, because the substitution also changes the lactose and total solids composition. The enthalpy results further demonstrate that the thermal response was not a simple dose-dependent change. Lapčíková *et al*. (2022) reported a melting enthalpy of 19.91 J/g for the control, compared with 3.90, 9.85, 2.87, and 2.90 J/g for the formulations containing 2.5, 5.0, 7.5, and 10% whey powder, respectively. The non-monotonic pattern suggests that the thermal transitions were

influenced by the overall formulation and the structure of the fat phase. The study also detected a whey-protein denaturation peak at approximately 86 °C, separate from the lower-temperature cocoa-fat melting transition (Lapčíková *et al*., 2022).

Different results were reported in high-protein chocolates formulated with WPI and erythritol. Nastaj *et al*. (2022) observed improved resistance to melting in untempered, sugar-free dark chocolate as WPI was incorporated. In a later study of white chocolate, increasing WPI levels were also associated with higher resistance to melting during the thermal stability test (Nastaj *et al*., 2024). These findings may appear different from the reduction in melting temperatures reported for whey-powder milk chocolate, but the formulations and methods were not the same. Lapčíková *et al*. (2022) measured thermal transitions by DSC after replacing part of the skim milk powder, whereas Nastaj *et al*. (2022, 2024) used WPI and erythritol in specially reformulated chocolates and evaluated melting stability using a different method. The comparison shows that dairy-protein ingredients do not have one fixed effect on confectionery melting behavior. Ingredient type, concentration, sweetener system, fat composition, tempering history, and test method all influence the result. DSC provides onset, peak, and endset temperatures and melting enthalpy, whereas a thermal stability test evaluates changes in the product during exposure to a selected temperature. These measurements describe related but different properties and should not be treated as interchangeable. For this reason, studies of protein-enriched confectionery should state the formulation, processing, and test conditions clearly before claiming improved melting stability (Lapčíková *et al*., 2022; Nastaj *et al*., 2024; Lipkin *et al*., 2025).

RESEARCH GAPS AND FUTURE PERSPECTIVES

Research on dairy-protein fortification has demonstrated that whey protein ingredients can be incorporated into chocolate, but the available product-level evidence is still concentrated in a relatively small number of formulations. Rakin *et al*. (2023) examined milk chocolate containing WPC and its trypsin hydrolysate, while Nastaj *et al*. (2022, 2024) studied high-protein dark and white chocolates formulated with WPI and erythritol. These studies provide useful results on flow, texture, melting, and microstructure; however, they do not establish how the same ingredients will behave in caramel, toffee, nougat, or other sugar-based confectionery. The quality attributes of soft confectionery are strongly linked to ingredient–process interactions, and these relationships need to be established for each product type rather than inferred from chocolate alone (Gunes *et al*., 2022).

A further limitation is that the effects of individual formulation variables are not always easy to separate. In the high-protein chocolate studies, WPI was used together with erythritol, and the formulations differed in more than one compositional feature (Nastaj *et al*., 2022, 2024). It is therefore difficult to attribute every observed change solely to the protein ingredient. Future work should use suitable control formulations and experimental designs that vary protein type and concentration independently, while keeping the sweetener system, fat content, and processing conditions appropriately controlled. Direct comparisons of WPC, WPI, hydrolysates, MPC, and casein-rich ingredients within the same confectionery matrix are also limited. The interactions responsible for changes in flavor and texture remain another important gap. Whey proteins can interact with lipids, carbohydrates, other proteins, and added flavor compounds, while pH, temperature, and ionic strength may alter these interactions. Ziebart and Du (2026) identified insufficient evidence on several of these matrix effects and noted that instrumental measurements do not always correspond clearly with sensory responses. This limitation is especially relevant to confectionery, where cocoa solids, sugar or sugar replacers, fats, and flavorings are present together. Studies using simplified model systems are useful for understanding mechanisms, but their findings need to be tested in complete formulations under realistic processing and storage conditions (Lipkin *et al*., 2025; Ziebart and Du, 2026).

Long-term quality and consumer response also require more attention. Protein addition may change flavor release, off-note development, texture, and melting behavior during storage, yet short-term laboratory measurements cannot establish whether these characteristics remain acceptable throughout shelf life (Ziebart and Du, 2026). In related protein-enriched frozen desserts, Mykhalevych *et al*. (2026) highlighted sensory and textural trade-offs, differences among protein ingredients, a lack of consistent assessment methods, and limited industrial-scale validation. Although frozen desserts are not identical to chocolate or cooked sugar confectionery, these issues point to the need for stronger consumer testing and pilot-scale studies across protein-enriched confectionery products. Future development is likely to depend less on simply increasing the protein percentage and more on choosing ingredients that work with the structure of each product. One promising direction is the design of dairy-protein particles with functions beyond conventional protein fortification. Zhou *et al*. (2026) demonstrated that engineered whey-protein hydrogel and microgel particles could structure sunflower oil into oleogels, which were then used to replace part of the cocoa butter in chocolate; the resulting chocolate showed a higher melting point, lower hardness, and improved lubrication under simulated oral conditions compared with the control. A related approach using WPC-stabilized walnut-oil oleogels also reported improved thermal stability and bloom resistance in chocolate (Yang *et al*., 2025). These studies suggest opportunities to combine protein delivery with fat structuring, although the nutritional, sensory, and shelf-life consequences need to be evaluated in the final product rather than inferred from the ingredient system alone.

Extending research beyond chocolate remains essential. Direct evidence for dairy-protein fortification in caramel, toffee, nougat, and other cooked sugar confectionery is less developed than the evidence for chocolate and frozen desserts. These products require studies that consider the effects of cooking temperature, moisture concentration, sugar chemistry, and protein heat stability on texture, color, and flavor. Work in ice cream also indicates that the type of protein and the composition of the surrounding matrix can create sensory and structural trade-offs, reinforcing the need for product-specific optimization rather than a single standard formulation (Mykhalevych *et*

al., 2026). Finally, future research should move toward pilot-scale validation, ingredient cost assessment, clear labeling, and credible sustainability evaluation. Novel and value-added dairy proteins may broaden the range of ingredients available to formulators, but consumer acceptance will depend on flavor, texture, affordability, and confidence in the product information (Liu *et al*., 2024). Studies should also report complete formulations, serving size, protein quality where measured, storage conditions, and the methods used to assess sensory and physicochemical properties. A common set of measurements for rheology, texture, color, melting behavior, water activity, sensory acceptance, and storage stability would make results easier to compare. Such an approach would help identify which protein-enriched products offer a practical nutritional contribution without losing the characteristics that consumers expect from confectionery.

CONCLUSION

Dairy proteins offer a practical means of increasing the protein content of confectionery while retaining familiar product formats such as chocolate and other sweets. Whey protein concentrates, isolates, hydrolysates, and casein-rich ingredients differ in composition and functionality; consequently, their suitability depends on the formulation and the role required from the ingredient (Carter *et al*., 2021; Nayik *et al*., 2024). Their use should therefore be considered not simply as nutrient addition, but as a reformulation step that may also influence processing and finished-product quality. The studies reviewed show that protein enrichment can alter important quality attributes, including viscosity, texture, microstructure, and melting behavior. In milk chocolate, WPC and its hydrolysate increased viscosity, although the measured hardness and major sensory characteristics were not significantly affected under the conditions studied (Rakin *et al*., 2023). High-protein dark and white chocolate formulations containing WPI and erythritol also showed changes in mechanical, surface, and melting characteristics (Nastaj *et al*., 2022, 2024). These findings demonstrate the potential of dairy proteins in confectionery, but they also show that the direction and extent of change depend on the protein ingredient, sweetener system, fat composition, and processing conditions. A higher protein level should not automatically be interpreted as an improvement in every aspect of product quality. From a nutritional perspective, dairy proteins can improve the protein contribution of a confectionery product; however, the overall nutritional value must be judged from the final formulation, including its sugar, fat, energy content, and serving size. Equally, acceptable flavor, texture, melting behavior, and storage stability remain essential for consumer acceptance. These considerations are particularly important because confectionery quality depends on interactions between ingredients and processing, while chocolate structure and rheology are closely linked to its physical and sensory properties (Gunes *et al*., 2022; Lipkin *et al*., 2025).

Overall, the available evidence supports the feasibility of dairy-protein enrichment, particularly in chocolate, but further product-specific research is needed for caramel, toffee, nougat, and other confectionery systems. Future studies should compare dairy protein ingredients under controlled formulations and report nutritional composition, processing behavior, physicochemical properties, sensory response, and shelf-life performance together. Such an approach will help identify formulations that provide a meaningful protein contribution without compromising the characteristics that consumers expect from confectionery.

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Author contributions- *T. Haarshiny: Conceptualization, literature review, collection of relevant literature, and writing – original draft preparation. A. Magesh: Supervision, conceptualization, and critical revision of the manuscript. K. Mugilan: Literature analysis, interpretation, organization of the review, and writing – review and editing. D. Rajkumar: Supervision, validation, and critical review of the manuscript. All authors have read and approved the final manuscript.*

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Table 1. Comparison of selected experimental studies on protein-enriched chocolate and frozen desserts.

Product or study	Protein ingredient and level	Main reported finding	Citation
Milk chocolate	WPC or trypsin-hydrolyzed WPC; 6% addition	Viscosity increased from 3.53 Pa·s (control) to 9.17 Pa·s (WPC) and 11.81 Pa·s (hydrolyzed WPC); hardness and enthalpy were not significantly changed.	Rakin *et al*. (2023)
Sugar-free dark chocolate	WPI + erythritol; 16%, 20%, 24% protein	Higher WPI levels altered surface and microstructure and improved resistance to melting in the tested formulations.	Nastaj *et al*. (2022)
Sugar-free white chocolate	WPI + erythritol; 12%, 16%, 20%, 24% protein	Higher WPI levels increased structural and mechanical responses and melting resistance; color changes were relatively small.	Nastaj *et al*. (2024)
Ice cream	MCC, buttermilk protein concentrate, or WPC80; skim milk powder control	Protein preparations changed consistency, hardness, overrun, and melting rate; the WPC formulation scored lower for some sensory attributes.	Kiełczewska *et al*. (2025)
High-protein frozen dessert	6% MPC, sodium caseinate, or WPI	Protein structure affected the development of ice, air, and fat networks; emulsifier addition altered microstructure and melting stability.	VanWees *et al*. (2026)

Note: Product-specific findings are summarized from the cited studies. WPC, whey protein concentrate; WPI, whey protein isolate; MCC, micellar casein concentrate; MPC, milk protein concentrate.

Table 2. Functional roles of dairy proteins and the strength of confectionery-specific evidence.

Functional role	Mechanistic basis	Evidence in confectionery	Interpretation and citation
Rheology and flow	Protein addition or hydrolysis changes how particles and ingredients interact in the chocolate mass.	At 6% addition, viscosity rose from 3.53 Pa·s (control) to 9.17 Pa·s (WPC) and 11.81 Pa·s (hydrolyzed WPC).	Strong direct evidence for this milk-chocolate formulation; processing implications must be tested (Rakin *et al*., 2023).

Functional role	Mechanistic basis	Evidence in confectionery	Interpretation and citation
Texture and network formation	Heat response, aggregation, and protein–ingredient interactions can support or disrupt structure.	Higher WPI in untempered, erythritol-containing white chocolate was associated with a denser network and higher mechanical responses.	Direct evidence in specific reformulated white chocolate; multiple ingredients changed (Nastaj *et al*., 2024).
Melting and surface stability	Changes in solid-phase packing and matrix organization affect melt resistance and bloom behavior.	WPI plus erythritol improved melting resistance and showed anti-blooming effects in the tested dark and white chocolates.	Promising but formulation-dependent; the result cannot be attributed to WPI alone (Nastaj *et al*., 2022, 2024).
Emulsification and interface stabilization	Amphiphilic protein regions interact with fat–water interfaces; caseins and whey proteins differ in interfacial behavior.	Potentially relevant to cream fillings and praline centers; limited direct evidence for finished confectionery.	Mechanistic evidence from broader food systems; validate in the target product (Nayik *et al*., 2024; Rodrigues *et al*., 2026).
Interactions with other ingredients	Non-covalent association can change protein structure and the behavior of polysaccharides, polyphenols, and other components.	The outcome may differ with the type and level of cocoa solids, sweetener, and other formulation ingredients.	Useful framework, but the direction of effect must be determined experimentally (Kong *et al*., 2022).

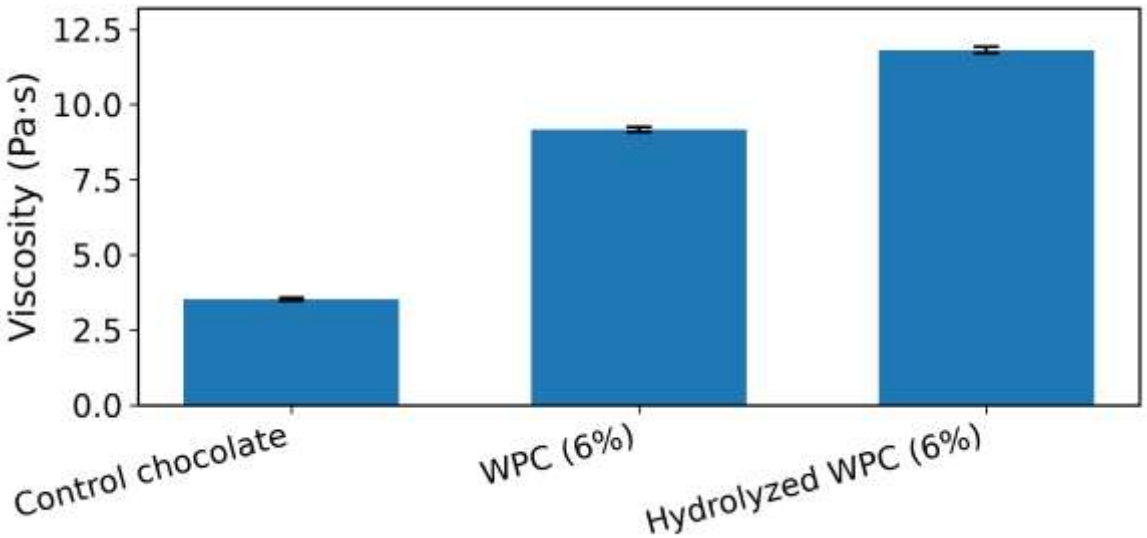


Figure 1. Reported apparent viscosity of control milk chocolate and chocolate containing 6% WPC or 6% hydrolyzed WPC. Bars show published means and error bars show the reported variation (Rakin *et al*., 2023).

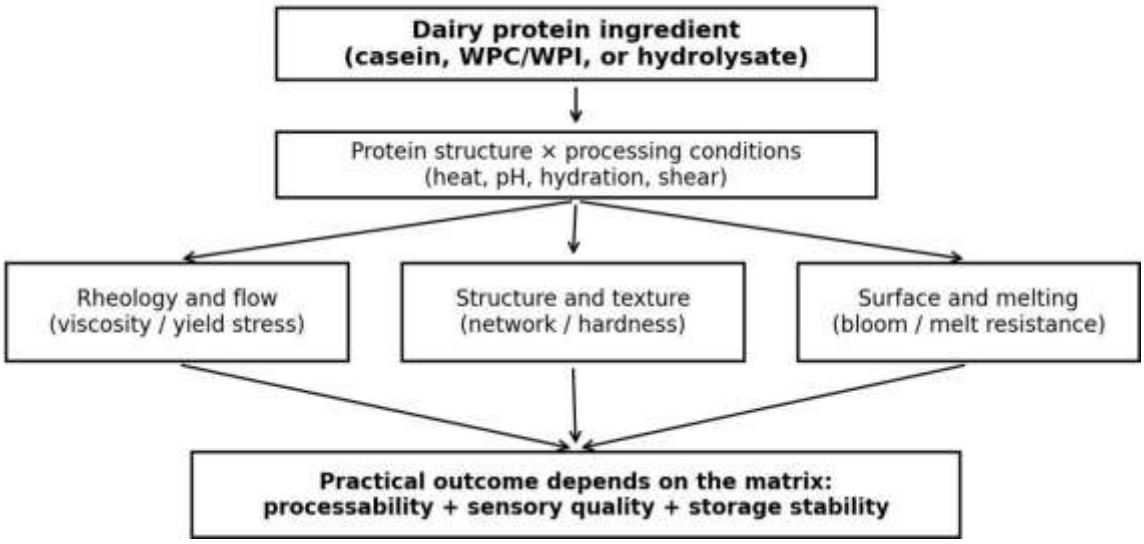


Figure 2. Conceptual synthesis of the links between dairy-protein ingredient structure, processing, and confectionery quality. This is a review schematic, not an experimental dataset (Kong *et al*., 2022; Nayik *et al*., 2024; Rodrigues *et al*., 2026).

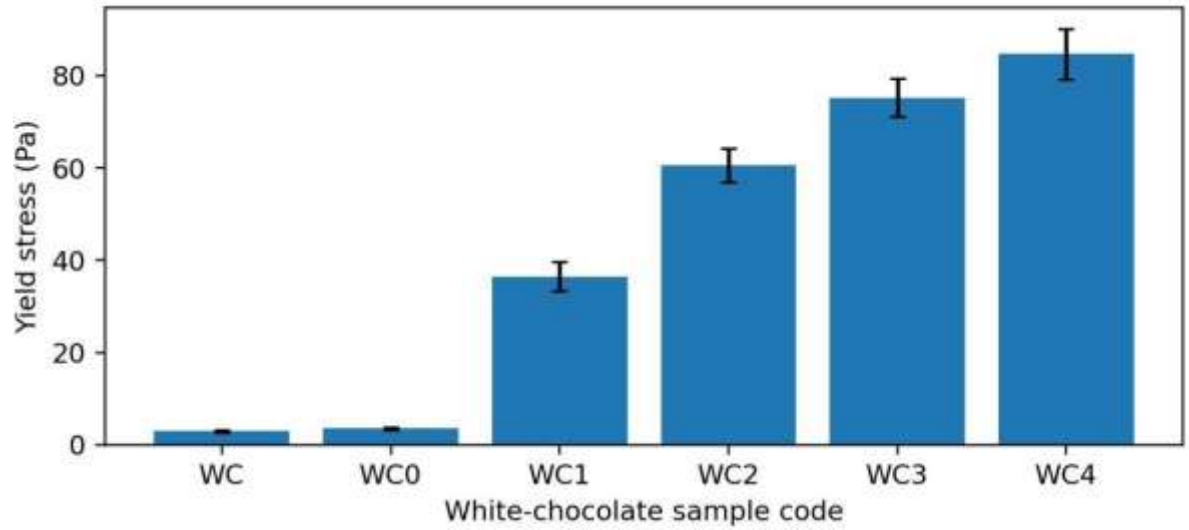


Figure 3. Yield stress of white-chocolate samples reported by Nastaj *et al*. (2024). WC, sucrose control; WC0, erythritol control without WPI; WC1–WC4, formulations containing 12%, 16%, 20%, and 24% protein, respectively.

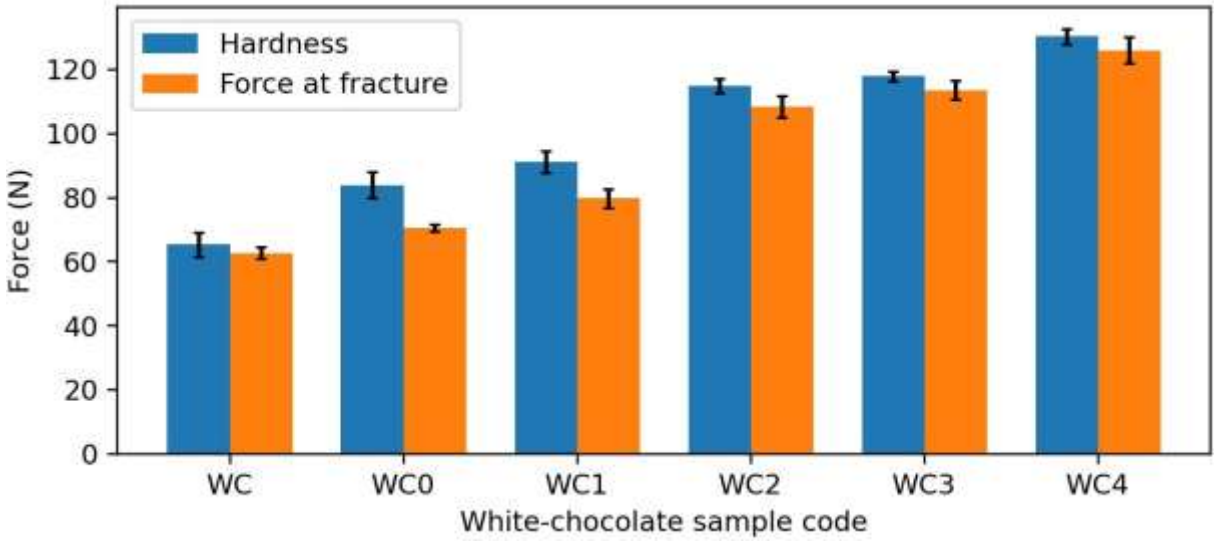


Figure 4. Hardness and force at fracture in the white-chocolate formulations. Values and error bars are reproduced from Nastaj *et al*. (2024).

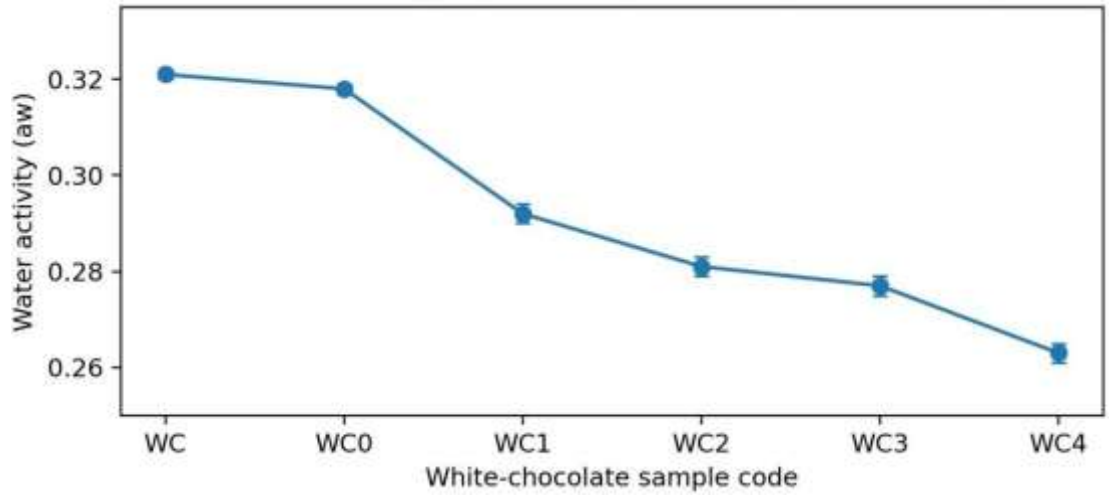


Figure 5. Water activity in the white-chocolate formulations reported by Nastaj *et al*. (2024). Error bars show the reported variation.

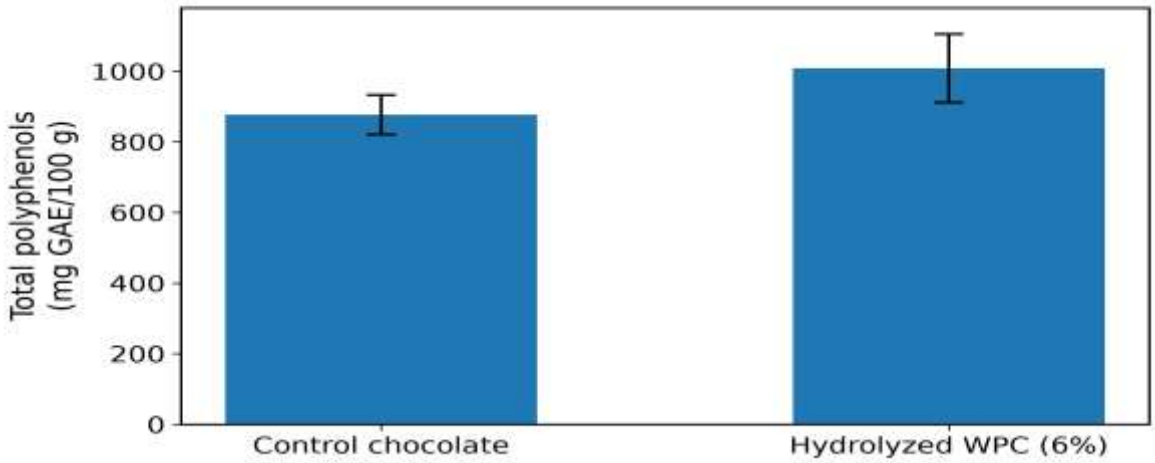


Figure 6. Total polyphenol content of control milk chocolate and chocolate containing 6% hydrolyzed WPC, as reported by Rakin *et al*. (2023). Values are study-specific and do not by themselves demonstrate a clinical health benefit.

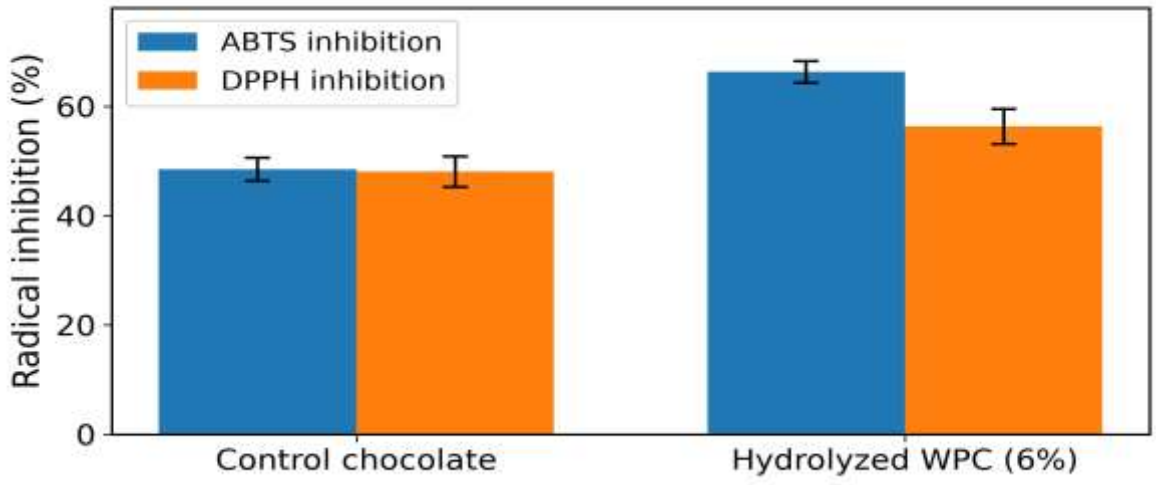


Figure 7. ABTS and DPPH radical-inhibition results for control milk chocolate and chocolate containing 6% hydrolyzed WPC. These are in vitro assay results and should not be interpreted as direct evidence of health effects in humans (Rakin *et al*., 2023).

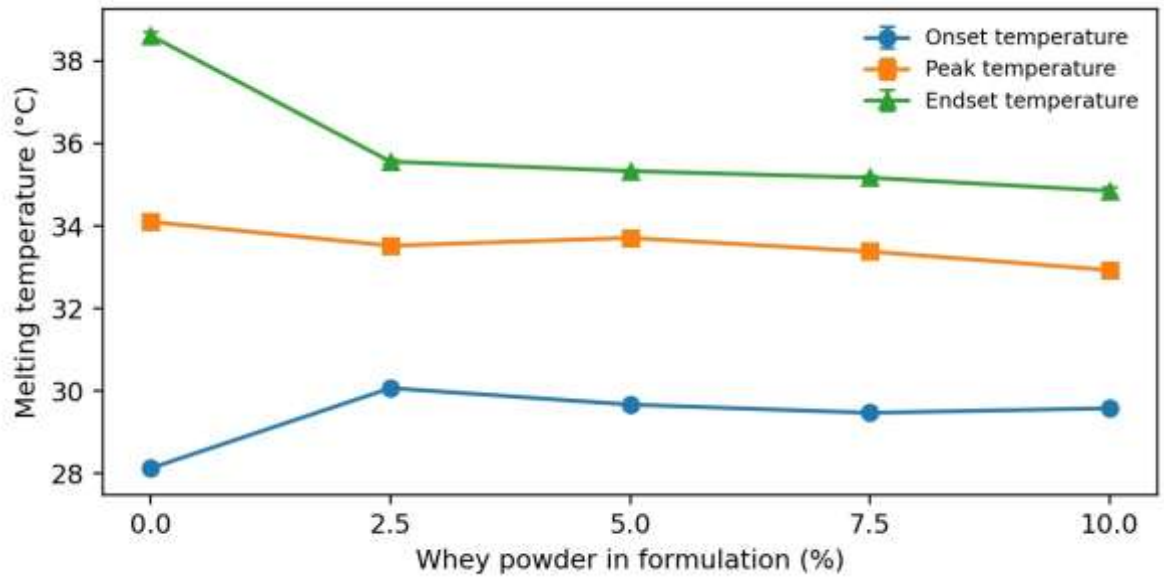


Figure 8. DSC melting parameters of milk chocolate containing 0–10% whey powder in place of part of the skim milk powder (Lapčíková *et al*., 2022).