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Research Article

The Untold Benefits of Using Milk as Base for Traditional Indian Carrot "Gajar-Halwa" Pudding

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Abstract

Halwas, which are vegetable, lentil, and cereal-based puddings, have a prominent place in Indian desserts. Traditionally, many of these *halwas* incorporate milk into their recipes. Milk offers more than just its well-known nutritional value in terms of fats, proteins, and vitamins. The aim of this review is to expound the rationale of using milk in view of recent studies that acknowledge milk proteins for their versatility in carrying hydrophobic phytochemicals. This capability allows for the effective delivery of otherwise insoluble phytoconstituents found in vegetables and cereals, thereby enhancing their bio-accessibility. Milk lipids also play a role in solubilizing and encapsulating certain phytochemicals. Thus, using milk as base in the carrot pudding results in the enhanced bioavailability of essential phytoconstituents such as carotenes, flavonoids and polyphenols present in carrots. This greatly enhances the spectrum of health benefits offered by the carrot *halwa* pudding.

Keywords: Carrot *halwa*, carrot pudding, milk pudding, milk protein phytochemical carriers, milk proteins encapsulating devices, milk fats phytochemical

Abbreviations: MFGM: Milk fat globule membrane; B-CN: β-casein; BTP: Black tea polyphenols; OZ439: anti-malarial compound artefenomel.

Introduction

Milk has been a long-standing ingredient in food preparations due to its nutritional value and pleasing taste. In the Indian subcontinent, milk has been utilized for millennia in a variety of delectable sweet and dessert dishes. Traditionally, these preparations were considered nutritious primarily due to the high protein and fat soluble vitamin content of milk. However, recent studies have revealed that the value of milk in these culinary creations extends far beyond these commonly known parameters. Use of milk may offer a range of benefits that include, but are not limited to, anti-oxidant, anti-inflammatory, anti-ageing and anti-cancer effects.

Research conducted over the past three decades has shed light on the significance of milk solids as effective carriers for various phytochemical components in fruits and vegetables. It is now widely acknowledged that bovine milk proteins and milk protein aggregates serve as crucial nano-vehicles that can be employed as carrier systems [1,2]. These proteins, owing to their predominantly hydrophobic structure, offer a natural means of transporting hydrophobic bio-active compounds. In addition to milk proteins, milk fats and the milk fat globule membrane (MFGM) also play a vital role in carrying phytochemicals. Together, milk proteins, milk fats and MFGM form an efficient system for enhancing the bioavailability and bio-accessibility of phytonutrients [1]. When milk solids are incorporated into the traditional preparation of carrot, beetroot, pumpkin and lentil *halwas* (puddings), they serve as effective carriers for delivering the abundant phytoconstituents present in these food items to various organs in the body.

Milk Proteins: Versatile Carrier Systems and Encapsulating Devices for Hydrophobic Compounds and Polyphenols

Milk is composed of two main proteins, namely casein (80%) and whey (20%), which contribute to its structural integrity and functional properties [3]. During the cheese-making process, heated milk undergoes a transformation where the added enzymes or acids cause the casein proteins to coagulate, resulting in a solid state separate from the liquid. The remaining proteins present in the liquid portion are referred to as whey proteins. The whey protein fraction consists of several proteins including α-lactalbumin, beta-lactoglobulin, serum albumin, and immunoglobulins. In terms of casein, there are four major constituents αs1-casein, αs2-casein, β-casein, and κ-casein alongwith a minor component called γ-casein. The typical concentrations of these casein constituents in milk are is 38% αs1-casein, 10% αs2-casein, 36% β-casein ,13% κ-casein and 3% γ-casein [3].

Types of Interactions of milk proteins with phytoconstituents

Milk proteins possess a high content of hydrophobic sites, allowing them to readily bind with various hydrophobic molecules exhibiting different levels of affinity [4]. These interactions, encompassing hydrophobic interactions, hydrogen bonds, van der Waals forces, and covalent bonds, play a crucial role in facilitating the binding of milk proteins to various phenolic components (Figure 1). In the major form of non-covalent binding, hydrophobic molecules establish hydrogen bonds with binding sites located on the protein surface. This mechanism proves advantageous for the efficient transport of hydrophobic forms of phenolic compounds, vitamins, and fatty acids [6]. The covalent interaction between milk proteins and (poly)phenols usually occurs through bonding of the C-N or C-S groups (Figure 1).

Milk proteins, particularly casein proteins, form large micelles in association with calcium phosphate [Figure 2]. These micelles possess a combination of hydrophobic and hydrophilic amino acids, making them effective at encapsulating hydrophobic compounds [7]. Utilizing milk proteins as encapsulation systems can enhance the properties of various polyphenols such as green tea polyphenols, rutin, eugenol, quercetin, resveratrol, dihydromyricetin, and cyanidin-3-O-glucoside, thereby increasing their bioavailability [8]. The hydrophilic characteristics of the micelle surface facilitate interactions with the gastrointestinal environment, promoting efficient absorption of the encapsulated compounds [2,9-11].

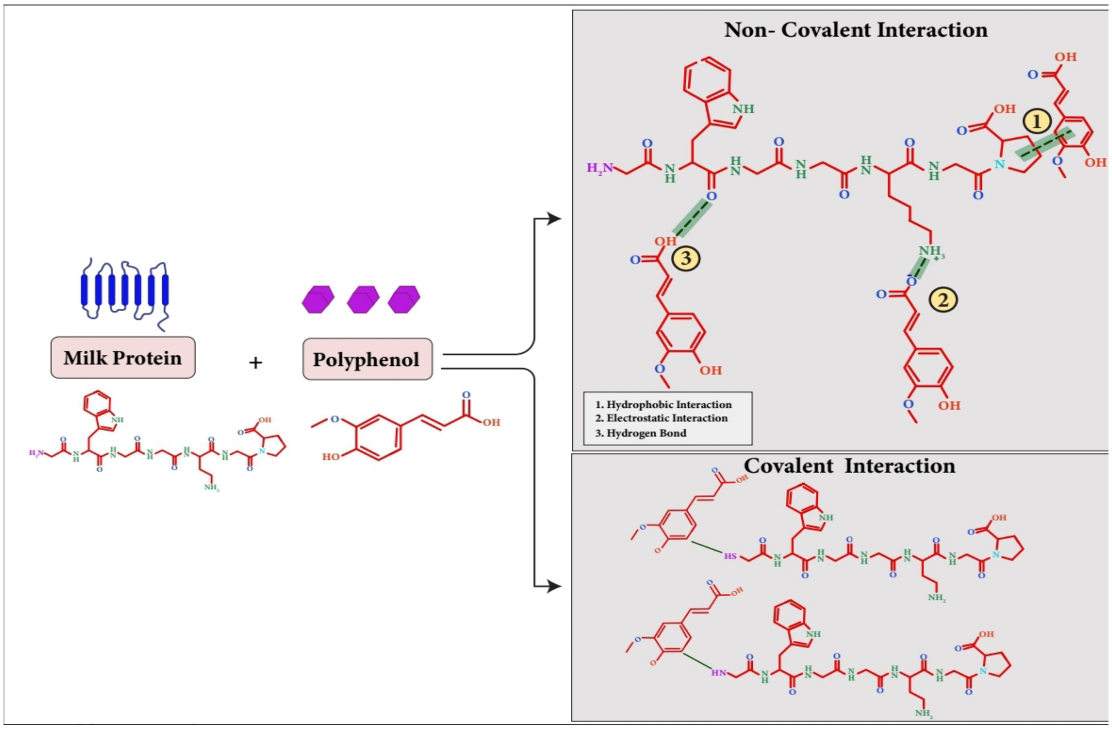

Figure 1: Types of interactions of milk proteins with phytochemicals. The interactions can be both covalent and non-covalent, the latter being of further three types: hydrophobic, electrostatic and through hydrogen bonds [5].

Interactions of Milk Proteins with various types of Phytochemicals

The following is a list of different types of milk proteins and their interactions with various phytochemicals:

Casein Proteins: These interact with grapes and cranberry polyphenols, namely catechin, tannic acid, homovanillic acid, and hesperetin as shown by Han et al. Their study found that casein proteins had a higher affinity for these polyphenols compared to whey proteins. The higher affinity of these polyphenolic compounds with casein proteins was correlated with the high recovery potential of polyphenolic compounds in the cheese-making process as caseins are the main proteins in cheese curd [12].

Casein micelles: Casein micelles make up approximately 80% of the proteins in milk. A study conducted by Gallo et al. in 2013 revealed that casein can bind to cocoa polyphenols, specifically catechin and epicatechin, through both covalent bonding and non-covalent interactions [Figure 2]. Antioxidant activity assays showed a significant effect of the various milk protein fractions in decreasing the in vitro antioxidant activity of polyphenols, suggesting the existence of other types of protein–polyphenol interactions, probably weaker non-covalent bonds [13].

α-caseins and β-caseins: The milk proteins α-casein and β-casein also interact with various phytochemicals. El-Messery et al. investigated the interactions between coffee polyphenols (tannins) and α-caseins and β-caseins. They found that the interactions between polyphenols and milk proteins are influenced by the pH level of the environment. Specifically the study found that at pH5, there was an optimal condition for maximum interaction between polyphenols and milk proteins. At this pH, the polyphenols and milk proteins formed insoluble complexes [14].

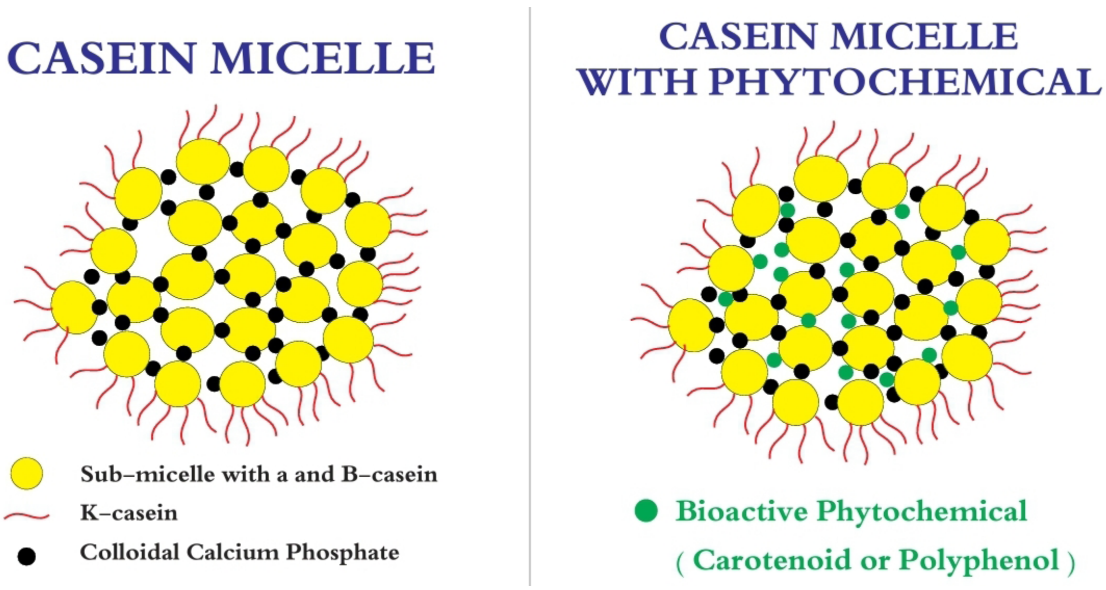

Figure 2: All casein peptides are amphiphilic. Amphiphilic peptides carry negative charge on their surface and tend to bind nanoclusters of amorphous calcium phosphate. Due to these properties casein molecules agglomerate into colloidal spherical micelles consisting of casein sub-micelles. The micellar complexes are surrounded by a hairy layer of k-casein. The amphiphilic peptides in the casein micelles can interact with both hydrophobic and hydrophilic polyphenols.

Similarly, antioxidant phenols such as resveratrol, genistein, and curcumin were also found to have a high binding affinity with α-casein and β-casein (B-CN) proteins, through both hydrophilic and hydrophobic interactions [9,15]. The study by Esmaili indicated that B-CN encapsulation increased curcumin solubility by at least 2500-fold, with hydrophobic interactions playing a significant role in the formulation. Encapsulation of curcumin in B-CN micelles also augmented its antioxidant activity and cytotoxicity against the human leukemia cell line K-562 [9].

Whey Proteins

Whey proteins interact with Black tea polyphenols (BTP) and green tea polyphenols such as catechin. Fourier transforms infrared spectroscopy (FTIR) analysis performed by Ye et al. showed that intense hydrophobic interaction was observed in the BTP–milk system [16].

β-lactoglobulin: In a study conducted by Kanakis et al., the interaction between β-lactoglobulin and tea polyphenols including catechin, epicatechin, epigallocatechin, and epigallocatechin gallate was investigated. Molecular modeling techniques were employed to analyze the complexation between polyphenols and the protein, revealing the involvement of multiple amino acid residues and the formation of an extended hydrogen bonding network. The findings of the study demonstrated that β-lactoglobulin has the potential to serve as a carrier for tea polyphenols [17].

Release and Swelling Behavior of Milk Proteins

The release of a carried substance from casein and whey proteins is influenced by the pH (potential of hydrogen) of the surrounding environment which affects the swelling behavior of these proteins. An increase in the swelling behavior of the proteins results in a higher release rate of the carried substance [4]. At a low pH, such as 1.2, the swelling behavior of casein is reduced, leading to a low release rate of the carried substances. However, as the pH increases towards a neutral level (7.4), the swelling behavior and release rate of casein significantly increase. On the other hand, whey proteins exhibit minimal swelling behavior around their isoelectric point. Consequently, the release rate of whey proteins is higher above the isoelectric point compared to when it is below [18]. In an in vitro experiment, the release of β-carotene from protein-stabilized emulsions was investigated. It may be noted here that milk behaves as an emulsion because of its fat content. At gastric conditions with a pH of 2.0, β-lactoglobulin exhibited a higher release rate. This can be attributed to increased proteolysis and the presence of pepsin, which facilitated the release. On the other hand, sodium caseinate- based emulsions showed a lower release rate, while lactoferrin-based and α-lactalbumin emulsions exhibited the least release under gastric conditions. However, at duodenal pH of 5.3, many protein types demonstrated high release rates [4].

A study conducted by Liu et al. (2014) and Yi et al. (2015) investigated the encapsulation and release of β-carotene in different stages of digestion, shedding light on the role of milk proteins as carriers for phytochemicals [19,20]. The researchers found that β-lactoglobulin emulsion exhibited the highest release rate in the gastric environment and demonstrated effective micellization of β-carotene in the simulated intestine. Sodium caseinate, on the other hand, displayed the highest release rate in the duodenal environment. Notably, β-lactoglobulin, sodium caseinate, lactalbumin, and lactoferrin protein fractions showed the highest release rates in the intestinal environment [19,20]. These findings highlight the potential of milk proteins and lipids in delivering and stabilizing various phytochemicals, including those present in carrots.

Milk Lipids as Carriers for Enhancing Bioavailability of Phytochemicals and Medicinal Compounds

Milk fats can play a vital role in the solubilization and absorption of drugs and phytoconstituents found in vegetables and cereals. This effect becomes pronounced especially during the process of digestion of milk fats. This is well illustrated by a study conducted by Salim et al., on the impact of milk fat digestion on the solubilization of the anti-malarial compound artefenomel (OZ439). The researchers conducted real-time monitoring of crystalline OZ439 in suspension during in vitro intestinal lipolysis of milk containing OZ439. The study revealed that OZ439 transformed into an unstable solid-state intermediate free base form (OZ439-FB form 1) at the pH of the intestines. Prior to the lipolysis process, milk fat globules facilitated the partial solubilization of OZ439-FB form 1. Subsequently, during the in vitro digestion process the free base form 1 dissolved, followed by the recrystallization of OZ439 into a more stable polymorphic form known as OZ439- FB form 2. These findings indicate that milk-based lipid formulations, by promoting the development of colloidal structures facilitated by the digestion of milk lipids, can significantly decrease the crystalline content of OZ439 compared to formulations lacking lipids. Consequently, milk could be considered an optimal lipid-based formulation for oral bioavailability of OZ439, along with increased nutritional value and therapeutic benefits [21].

Verma et al. conducted a study to explore the potential of milk lipids in delivering and stabilizing various phytochemicals. They focused on micro fluidized nano-curcumin emulsion using milk cream. The study revealed that this approach resulted in enhanced antioxidant activity and demonstrated no toxic effects on HepG2 cells, which are non-tumorigenic cells with high proliferation rates and an epithelial-like morphology that perform many differentiated hepatic functions [10]. The researchers also observed a significant improvement of 30% in bioaccessibility, highlighting the effectiveness of microfluidization as a technique and milk cream as a cost-effective carrier for creating stable and bioaccessible nano-curcumin emulsions [10].

Milk fat globules, which naturally occur, serve as carriers for fat-soluble vitamins present in milk. The membrane surrounding these globules, known as MFGM (Milk Fat Globule Membrane), has garnered considerable interest due to its complex composition and unique emulsifying and biological functionalities. The intact nature of milk fat globules enables them to resist gastric digestion, mainly due to the structural characteristics of the MFGM [1]. These distinctive properties of milk fat globules have a positive impact on the delivery process of hydrophobic bioactive compounds. Recent research has emphasized the potential of milk fat globules in facilitating the encapsulation process of both hydrophilic and hydrophobic compounds. These findings highlight the significant potential of milk fat globules as an innovative food ingredient for enhancing nutritional profiles [1].

Milk Proteins and Lipids as Phytochemical Carriers for Enhancing the Nutritional Profile of Carrot *Halwa*

In the process of preparing carrot *halwa*, carrots are typically grated or finely chopped and then cooked in milk (as depicted in Figure 3). As the milk simmers, a portion of its water content evaporates. Subsequently, sugar is added to the mixture, followed by further sautéing in ghee (clarified butter) until the desired *halwa* consistency is achieved. In this process milk serves as a medium for boiling the mashed carrots. The heat and moisture soften the carrot pulp and break down the thick cell walls, resulting in a smooth texture and the release of the phytochemicals stored inside the cells. Additionally, the presence of milk enables interactions between the bioactive compounds present in carrots and the various milk components by mechanisms described in sections 2 and 3. These interactions facilitate binding, encapsulation and stabilization of the phytochemicals. Boiling carrots in milk thus allows for the adsorption and transport of beneficial compounds in carrots such as carotenoids, by milk proteins and lipids, increasing their bioavailability [2].

The presence of lipids in milk contributes to its classification as an oil in water emulsion. During the initial stages of carrot *halwa* preparation, when the carrot pulp is boiled in milk, the milk fats have the capacity to absorb and bind hydrophobic phytochemicals found in the carrot pulp. As a result, carotenes and other absorbed bioactive compounds can be considered as components of an emulsion system. Studies have shown that emulsion-based carrier systems are efficient in transporting and releasing hydrophobic bioactives such as β-carotene [22]. By utilizing milk emulsion as a carrier for β-carotene in carrots, the bioavailability and overall health benefits of this important phytochemical can be significantly enhanced. Hence, by boiling carrots in milk, the beneficial compounds in carrots, including carotenoids, flavonoids and polyacetylenes bind with milk proteins and are absorbed by milk lipids, thereby providing a more bio accessible form of these nutrients [2]. This process enhances the overall nutritional profile of the dish.

Figure 3: The process of preparing carrot halwa is shown stepwise. Cooking the carrot pulp in milk is an essential step in the traditional method of making this delicacy.

Discussion

A significant amount of research has been conducted on the use of milk proteins and lipids as carriers for different types of phytochemicals [2,9,10,19,20,23-29]. These studies have contributed to our understanding of the mechanisms involved in enhancing the bioavailability of phytochemicals in carrots when combined with milk which is essentially an emulsion. Milk lipids, including triglycerides, phospholipids, and cholesterol, can serve as carriers for hydrophobic phytochemicals. These lipids can facilitate the transport and delivery of hydrophobic compounds, ensuring their absorption and bioavailability.

Milk proteins on the other hand, can employ various binding mechanisms, such as hydrogen bonds, hydrophobic interactions and van der Waals forces, to bind hydrophobic molecules such as fat-soluble vitamins, fatty acids and polyphenols. Distinct milk proteins, such as casein, β-lactoglobulin, α-lactalbumin, and bovine serum albumin, exhibit different binding capacities and mechanisms. Researchers have leveraged these milk proteins as carrier systems for hydrophobic substances in a range of studies. These include the encapsulation and stabilization of hydrophobic pharmaceutical ingredients, the binding of vitamins and fatty acids, and the protection of polyphenols against oxidation.

The milk proteins have the ability to interact with various phytochemicals present in carrots, including polyphenols and carotenoids, forming complexes that enhance their stability and bioavailability [30]. In some recipes, dry fruits such as almonds and raisins are also added in the beginning, and are cooked in the milk alongwith the carrot. The hydrophobic phyto-compounds in carrots and dry fruits can bind to the hydrophobic regions present on the surface or within the structure of milk proteins. This binding process is reversible, allowing for the delivery of polyphenols, vitamins, and fatty acids. Furthermore, hydrophilic bioactive molecules can attach to reactive sites, such as amino and thiol groups located on the surface or within the protein structure. This binding is irreversible. This protein-binding property of milk can also help in reducing the perceived bitterness associated with the consumption of polyphenolic compounds [4]. By incorporating both hydrophilic and hydrophobic bioactive compounds in milk a more effective delivery system can be achieved [2].

Additionally, another mechanism that enhances the delivery, bioavailability and stability of carrot bioactives in carrot milk pudding is, the formation of complexes between pectin, whey proteins and phenolic phytochemicals [11,31]. During the heating process, a portion of pectin in carrot pomace becomes solubilized, and this pectin partially coats the whey protein aggregates (Figure 4). The flavonoids and other polyphenols then bind to the pectin through covalent or non-covalent interactions. This food matrix contributes to the improved stability of the phytochemicals by protecting them against acid degradation in the stomach. Furthermore, the enhanced bioavailability of phytochemicals allows them to reach the large bowel, where they can exert beneficial effects on the existing gut flora [32]. This interaction between pectin, whey proteins, and phenolic phytochemicals in carrot milk pudding demonstrates the potential for developing food matrices that enhance the delivery and effects of bioactive compounds.

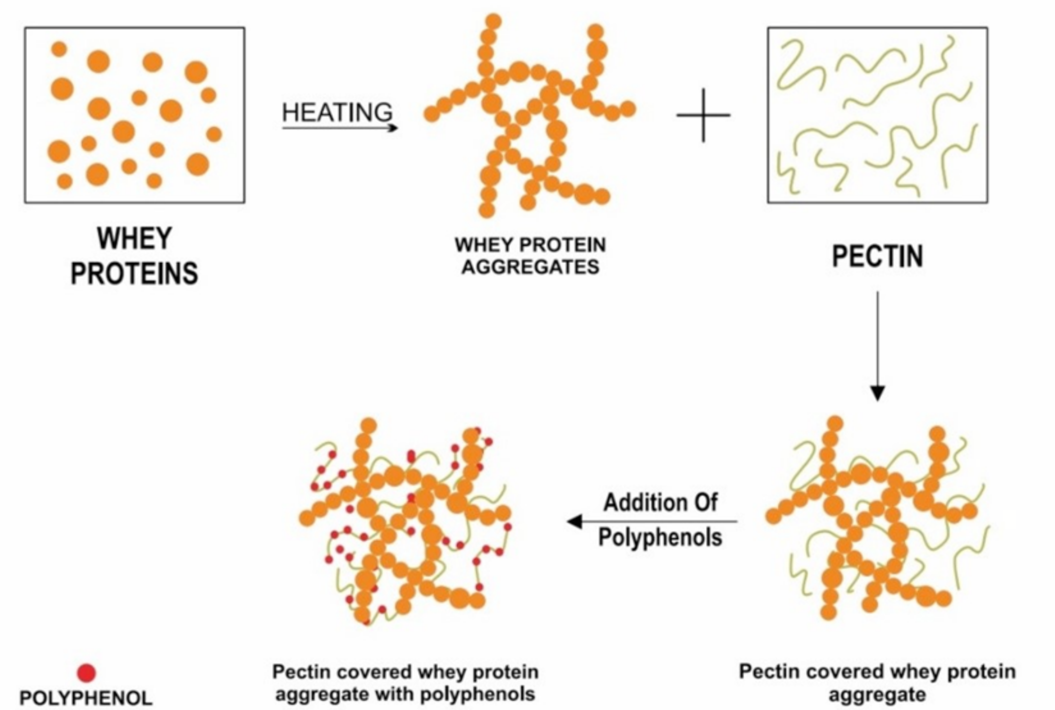

Figure 4: Whey protein aggregates are formed when milk is added to the pulped carrot and heated. The whey protein aggregates get coated with solubilized pectin fibrils to which the poylphenols get attached. This complex is stable and helps to enhance bioavailability of phytochemical.

Conclusion

The use of milk as a cooking medium and base in carrot *halwa* enhances the absorption of bioactive compounds found in carrots. This is because the phytochemicals are delivered in a more stable form and are more bioaccesible. Several studies have shown that milk proteins and lipids can act as carriers for phytochemicals, leading to improved solubility, antioxidant activity, and release properties [2-7,12-17]. This is because milk proteins can bind to both hydrophobic and hydrophilic phytochemicals by means of covalent and non-covalent interactions, and thereby enhance their transport, stability and absorption. Similarly, the milk cream fats can bind with phytoconstituents, forming lipid vesicles and emulsions [33]. By utilizing milk as a vehicle for delivering the bioactive compounds present in carrots, their nutritional value and health benefits are significantly enhanced. This approach can also be applied to the preparation of other halwa varieties, such as Calabash (Lagenaria siceraria), figs and almond halwas, offering similar benefits in terms of improved bioavailability and enhanced nutritional profiles.

Declarations

Ethics approval and consent to participate – Not applicable.

Consent for publication – I hereby give my consent.

Availability of data and material – Data (literature search) available with author

Competing interests- Not applicable

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