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Microencapsulation of vitamin C for functional MOCAF-based noodles

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Abstract. Vitamin C encapsulation technology offers an effective approach to enhancing nutrient stability during the heating process in MOCAF (modified cassava flour)–substituted noodles. This study aimed to obtain an optimal microencapsulation formulation of vitamin C using maltodextrin and CMC at ratios of (18.2:1.8)%, (18.5:1.5)%, (18.8:1.2)%, (19.1:0.9)%, and (19.4:0.6)%. The optimal formulation was subsequently applied to noodles produced using wheat flour and MOCAF in a 70:30 ratio. Evaluations included encapsulation efficiency (EE), surface morphology observed through Scanning Electron Microscopy (SEM), and vitamin C content of the fortified noodles. The best formulation (18.2:1.8) achieved an EE of 85.35 ± 4.24%. SEM analysis showed microcapsules with irregular and slightly collapsed surfaces characteristic of freeze-dried powders, with continuous, non-porous matrices and no visible vitamin C crystals on the surface, indicating effective core protection and supporting the high EE value. Noodles fortified with encapsulated vitamin C exhibited significantly higher vitamin C content (0.37 ± 0.06 mg/g) compared with noodles containing non-encapsulated vitamin C. These results demonstrate that microencapsulation effectively improves vitamin C retention under processing and highlights its potential application in developing MOCAF-based functional noodles. Future work may explore production scaling, storage stability, and consumer acceptance to support broader utilization of encapsulated functional ingredients.

1 Introduction

The development of functional foods through micronutrient fortification represents a critical strategy in public health nutrition, aimed at combating dietary deficiencies and enhancing the health-promoting properties of staple foods. Vitamin C (ascorbic acid), an essential water-soluble micronutrient, serves crucial biological functions as an antioxidant, in collagen synthesis, and immune regulation [1]. However, its practical application in food fortification is significantly constrained by molecular instability, with high susceptibility to

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degradation from oxygen, light, thermal processing, and extended storage [2] highlighting the need for innovative approaches in functional food development.

The growing consumer demand for functional foods coincides with the emergence of Modified Cassava Flour (MOCAF) as a viable alternative to wheat flour in noodle production, offering gluten-free properties and higher dietary fiber content [3]. Although noodles are typically associated with mineral fortification, vitamin C fortification in MOCAF based noodles presents considerable nutritional potential because MOCAF lacks naturally occurring antioxidants and essential vitamins. Incorporating vitamin C can enhance the functional value of MOCAF noodles by providing antioxidant benefits and supporting immune health, thereby addressing nutrient gaps commonly found in starch based products. However, vitamin C is highly sensitive to heat and oxidation, making its incorporation into noodle formulations challenging. Therefore, advanced stabilization methods particularly microencapsulation are required to protect vitamin C during processing and storage

Microencapsulation via freeze-drying offers an effective solution for stabilizing labile compounds, operating under low-temperature vacuum conditions that minimize thermal degradation [4]. This study employs a composite wall system of maltodextrin and Carboxymethyl Cellulose (CMC), leveraging maltodextrin's solubility and CMC's film-forming properties [5] to achieve optimal encapsulation efficiency and protective capacity, focusing on this novel combination for enhanced nutrient delivery.

This novel combination of maltodextrin and CMC through freeze-drying for noodle fortification represents a significant advancement in delivery systems, particularly since previous studies have primarily investigated vitamin C encapsulation using various wall materials with spray-drying techniques [6]. Recent advances in nutrient stabilization approaches [7] provide the foundation for this research investigation into optimized encapsulation methods.

This research investigation aims to develop optimized vitamin C microcapsules using maltodextrin-CMC through freeze-drying technology and implement in MOCAF noodle as fortification. The study establish to an innovative model for functional food development, focusing on enhanced nutrient stability and bioavailability in fortified food matrices.

2 Materials and Methods

2.1 Materials

Synthetic vitamin C, maltodextrin, CMC, aquades (distilled water), high-protein wheat flour, mocaf flour, eggs, salt, broth powder, cooked water, and cooking oil, laboratory glassware set, hot plate with magnetic stirrer, noodle mold and roller, stove, and noodle cooking utensils (pot, bowl, etc.).

2.2 Methods

2.2.1 Vitamin C Encapsulation

Vitamin C (99.0% w/w) microencapsulation was performed based on the method of [8] with modifications. Maltodextrin and CMC were prepared in ratios of (18.2:1.8)%, (18.5:1.5)%, (18.8:1.2)%, (19.1:0.9)%, and (19.4:0.6)% dissolved in aquades at 20% (w/v) concentration. The solution was stirred using a magnetic stirrer for 30 minutes at 25°C. Then, 50 ml of ascorbic acid solution was added to the MD-CMC solution. The resulting emulsion was further stirred using a magnetic stirrer for 60 minutes at 25°C with a speed of

8000 rpm. The mixture was dried using freeze-drying method by temperature -55ºC for 48 hours. Parameters analyzed for the encapsulated vitamin C included encapsulation efficiency (EE), determined using a method adapted from [6] and morphological analysis [9] using Scanning Electron Microscopy (SEM) Hitachi TM3000 with 5 kV acceleration voltage.

2.2.2 Production of Vitamin C-Fortified Mocaf Noodles

Noodle production followed the method of [10]. The ingredients used included 70 g high-protein wheat flour, 30 g mocaf flour (70:30 ratio), 2 g CMC, 7.5 g egg, 0.3 g salt, 0.2 g seasoning powder, 50 mL distilled water, and 5 mL cooking oil. All ingredients were mixed and kneaded until a smooth dough was obtained. To determine whether encapsulation effectively enhances the vitamin C content of the noodles, a comparative approach for the encapsulation of bioactive compounds was applied with modifications based on [11]. Two formulations of mocaf-based noodles were produced: one fortified with encapsulated vitamin C and the other with non-encapsulated (pure) vitamin C. The dough was rested for 30 minutes before molding. After resting, the dough was flattened and cut into noodle strands using a mold. The resulting noodles were dusted with a mixture of wheat and mocaf flour (70:30) to prevent sticking between strands.

2.2.3 Statistical Analysis

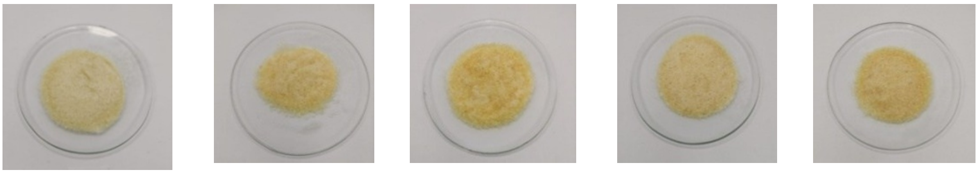
This research employed a Completely Randomized Design (CRD) with a single factor. Statistical differences among treatments were analyzed using one-way ANOVA followed by Duncan's multiple range test at a significance level of $p < 0.05$.

3 Results and Discussion

3.1 Development of Vitamin C Microcapsules with Maltodextrin and CMC

The microencapsulation of Vitamin C was performed to protect this essential but highly unstable nutrient from degradation. Vitamin C, or ascorbic acid, is notoriously susceptible to damage from environmental factors such as heat, oxidation, and light, which significantly limits its shelf life and efficacy in fortified food products . The process of encapsulation creates a protective barrier around the active compound, thereby enhancing its stability during processing and storage [6]. In this study, a freeze-drying method was employed to produce a stable powdered microcapsule.

The wall materials selected were a combination of maltodextrin and CMC. Maltodextrin is a common choice in the food industry for encapsulation via spray-drying and freeze-drying due to its high water solubility, low viscosity, and cost-effectiveness [12]. CMC was chosen as a secondary wall material for its excellent stabilizing properties. As a hydrocolloid, CMC enhances the viscosity of the solution and improves the structural integrity of the microcapsule wall, leading to better retention of the core material [13]. The combination of maltodextrin with other polymers like CMC has been shown to improve the protective capabilities of the capsule matrix [14]. As shown in Figure 1, the process transformed the initial liquid suspension into five formulations of dry, stable powders, ready for application.



(a) (b) (c) (d) (e)

Fig. 1. Vitamin C microcapsules with maltodextrin and CMC at ratios of (a) 18.2 : 1.8; (b) 18.5 : 1.5; (c) 18.8 : 1.2; (d) 19.1 : 0.9; and (e) 19.4 : 0.6

3.2 Analysis of Vitamin C Encapsulation Efficiency

Encapsulation Efficiency (EE) is a critical parameter that quantifies the percentage of the active core material (Vitamin C) successfully entrapped within the wall material matrix. A high EE value indicates a successful and efficient encapsulation process. In this study, the EE was determined using a UV-Vis spectrophotometer.

Table 1 shows that the wall material composition had a significant effect on encapsulation efficiency ($p<0.05$), with a clear trend indicating that encapsulation efficiency increased as the proportion of CMC in the wall material increased. The formulation with a maltodextrin to CMC ratio of 18.2:1.8 exhibited the highest EE of 85.35 ± 4.24 %. This superior performance can be attributed to the molecular properties of CMC. The carboxyl groups in CMC's structure can form hydrogen bonds with the hydroxyl groups of ascorbic acid. This molecular interaction creates a more stable and robust polymer matrix, effectively trapping the Vitamin C molecules and preventing their leakage during the freeze-drying process [15]. In contrast, formulations with lower CMC content had a less effective matrix, resulting in lower EE values.

Table 1. Encapsulation Efficiency Results

Wall Material Maltodekstrin : CMC (%)	**Encapsulation Efficiency (%)**
18.2 : 1.8	85.35 ± 4.24[a]
18.5 : 1.5	76.10 ± 3.65[b]
18.8 : 1.2	71.77 ± 4.12[b]
19.1 : 0.9	50.60 ± 2.24[c]
19.4 : 0.6	43.27 ± 2.95[c]

Note : Different letter notations (superscripts) in the same column showed significant differences ($p<0.05$)

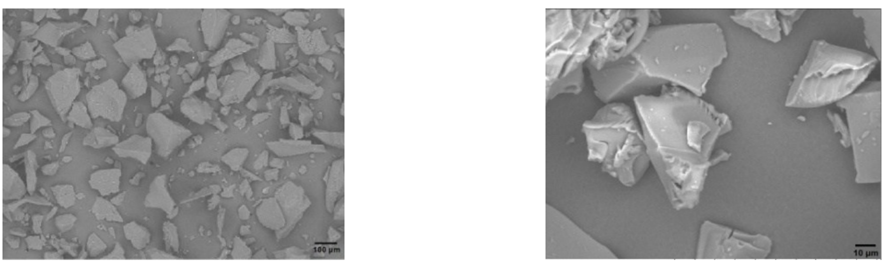
Before the drying process, the addition of Carboxymethyl Cellulose (CMC) to the encapsulation solution (Maltodextrin + CMC + Vitamin C) increases its viscosity. This is a known function of CMC in emulsions, where it enhances stability by modifying the rheological properties of the continuous phase. This thicker solution prevents the core material, Vitamin C, from moving freely and leaking out of the droplets during the atomization or spraying stage. A stable emulsion is crucial for ensuring that the Vitamin C is uniformly distributed within the encapsulant matrix [16]. Conversely, at low CMC concentrations, the solution is less viscous. This leads to less stable droplets during atomization, allowing Vitamin C to migrate to the droplet's surface before the capsule wall fully hardens, resulting in greater loss and lower encapsulation efficiency.

Maltodextrin is a common wall material but can sometimes be brittle and form a porous structure after drying. CMC mitigates this issue by acting as a "binder" or "net" among the maltodextrin molecules due to its long polymer structure. This creates a denser, stronger, and less crack-prone microcapsule wall that more effectively traps Vitamin C during the rapid drying process. The presence of CMC improves the strength of the interfacial film around the droplets, contributing to a more robust final microcapsule[16]. Without sufficient CMC, the wall formed primarily from maltodextrin is more fragile, and micro-cracks can form as water evaporates, creating escape routes for the Vitamin C.

At the molecular level, the key interaction is hydrogen bonding. Both CMC and Vitamin C (Ascorbic Acid) are rich in hydroxyl (-OH) groups, which are sites for this interaction [17]. This allows for the formation of hydrogen bonds between the CMC polymer chains and the Vitamin C molecules [18]. This intermolecular interaction helps anchor the Vitamin C within the polymer matrix, stabilizing it throughout the encapsulation process and preventing its degradation. Studies using FTIR spectroscopy and other techniques have confirmed that hydrogen bonding is a dominant force driving the adsorption and interaction of CMC with other surfaces and molecules, supporting this stabilization mechanism [19].

3.3 Scanning Electron Microscope (SEM) Analysis

To visualize the surface morphology of the most effective microcapsule formulation (18.2:1.8 maltodextrin:CMC), Scanning Electron Microscopy (SEM) was performed. The resulting images (Figure 2) reveal microcapsules with a relatively irregular and somewhat collapsed surface structure, which is characteristic of powders produced by freeze-drying and therefore contrasts with spray-drying, which usually produces smooth and spherical particles, whereas the freeze-drying process removes water via sublimation, often causing structural collapse or shrinkage of the matrix[12]. The surfaces appear continuous and non-porous, without visible cracks, suggesting that the vitamin C core is well-contained within the matrix. Furthermore, the images show no loose vitamin C crystals on the surface, confirming the high encapsulation efficiency measured previously. The particles were observed to have a relatively large size distribution, with an average diameter exceeding 100 μm.



(a) (b)

Fig. 2. Micrographs of the obtained encapsulates using a wall material ratio of 18.2:1.8 (maltodextrin:CMC) are presented at (a) 100× magnification and (b) 1000× magnification.

3.4 Fortification of MOCAF-Based Functional Noodles with Vitamin C Microcapsules

The optimal microcapsule formulation was used to fortify functional noodles made with a 70:30 blend of wheat flour and MOCAF (Modified Cassava Flour). The use of MOCAF is a strategic approach to reduce wheat dependency and increase the utilization of local food resources in functional food development. Noodles fortified with encapsulated Vitamin C were compared to those fortified with standard, unencapsulated Vitamin C powder (Figure 3).


(a)


(b)

Fig. 3. MOCAF noodles fortified with (a) Vitamin C powder and (b) Vitamin C microcapsules

As shown in Table 2, microencapsulation of vitamin C significantly affected ($p < 0.05$) vitamin C retention in noodles. Samples fortified with microencapsulated vitamin C exhibited higher vitamin C content (0.37 ± 0.06 mg/g) compared to those fortified with standard vitamin C powder (0.15 ± 0.01 mg/g). This result underscores the protective benefit of encapsulation. During noodle processing, which includes mixing and sheeting, unprotected Vitamin C is exposed to moisture and mechanical stress, leading to substantial degradation [20]. The microcapsule's wall material serves as a physical shield, minimizing these losses and ensuring a higher final nutrient content in the product. This improved retention is critical for delivering the intended health benefits of fortified foods, demonstrating that microencapsulation is an effective strategy for preserving heat- and water-sensitive vitamins in processed foods like noodles [10].

Table 2. Vitamin C content in MOCAF-based functional noodles (70:30 ratio)

Sample	Vitamin C Content (mg/gram)
Fortified with vitamin C powder	0.15 ± 0.01^{a}
Fortified with vitamin C microcapsules	0.37 ± 0.06^{b}

Note : Different letter notations (superscripts) in the same column showed significant differences ($p<0.05$)

4 Conclusions

Based on the results, the microencapsulation of vitamin C using a maltodextrin and CMC combination at a 18.2:1.8 ratio through freeze-drying successfully achieved high encapsulation efficiency (85.35 ± 4.24 %). The application of these microcapsules in MOCAF noodles significantly improved vitamin C content (0.37 ± 0.06 mg/g) compared to non-encapsulated vitamin C (0.15 ± 0.01 mg/g), demonstrating effective protection during processing. This encapsulation approach presents a viable strategy for developing functional foods with enhanced nutrient stability and bioavailability.

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Conflicts of Interest: The authors declare no conflict of interest.

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