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Encapsulation: strategy for β-carotene Preservation

Camila Duarte Ferreira-Ribeiro[1], Deborah Murowaniecki Otero[1]* and Itaciara Larroza Nunes[1,2]

[1]*Department of Food Science, Federal University of Bahia, Brazil*

[2]*Department of Food Science and Technology, Federal University of Santa Catarina, Brazil*

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***Corresponding author:** Deborah Murowaniecki Otero, Nutrition School, Department of Food Science, Federal University of Bahia, Brazil

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Introduction

β-carotene ($C_{40}H_{56}$) is one of the most important members of the carotenoid's family because of its high provitamin A activity, in which it has in its structure a double ring of unsubstituted beta-ionone. Furthermore, β-carotene has a strong antioxidant capacity by the sequestering reactive oxygen species, such as the singlet oxygen ($^1O_2$) and the peroxide radical (ROO●) [1].

This bioactive compound has a large number of conjugated double bonds in its structure, which makes it highly susceptible to chemical degradation when exposed to oxygen, light or heat during the production, storage, acid conditions, pro-oxidants or utilization of foods [2,3].

β-carotene intake has been shown to improve the immune system's response to infections and to reduce the incidence of certain chronic diseases [4,5]. Humans cannot synthesize β-carotene in their bodies, and so they must obtain it from the foods they consume. The potential health benefits of β-carotene may not be realized because of its relatively low oral bioavailability [6,7].

Despite the potential health benefits that may be gained from ingestion of this natural molecule, it is often difficult to incorporate β-carotene into functional food products because of its poor water solubility, chemical instability, and low bioavailability [8,9]. Therefore, it is necessary to seek some approaches to address this problem the encapsulation being a strategy to protect this compound.

Encapsulation is a process, which entraps one substance (active agent) into another substance, encapsulant, producing small capsules in the micrometer scale (up to 1000μm) or nanometer (nanoencapsulation - up to 1000nm) [10,11].

The encapsulated substance can be called the core, fill, active, internal or payload phase. The packaging materials are called the coating, membrane, wall material, capsule, carrier or shell, external phase, or matrix, which can be made of gums, proteins, modified and natural polysaccharides, lipids and synthetic polymers [11,12].

β-carotene Encapsulated has been employed by different purposes as described below:

Primarily, β-carotene encapsulation is associated with the stability improvement [13], because its chemical structure, predominantly unsaturated bounds, can promotes fast color, bioactive benefits losses, for instance;

It can be used to preserve the high provitamin A activity and antioxidant capacity [14,15] because this technology protects the shell material from degradation by reducing its reactivity to its outside environment (e.g., oxygen, heat and light) [11].

β-carotene encapsulated improve water solubility because it is insoluble in water and once encapsulated it becomes dispersible in hydrophilic foods, which increases the use in several food matrices [14,15].

This bioactive compound has been encapsulated to preserve its color [14-16] because the color maintenance is indicative that both the antioxidant activity and the provitamin A activity are preserved, which is considered important for the food fortification. Furthermore, β-carotene is a natural red-yellow pigment, which in addition to bringing potential health benefits, still allows the artificial colorants replacement [16]. Artificial colorants have been studied because them toxicological potential [17].

It has also been studied the encapsulation of β-carotene sources by the synergistic effect of this with the other carotenoids, because Nano encapsulated carotenoids are

mostly produced from these pigments in the isolated form [15], even there are the importance of the association of these compounds with each other, producing synergistic effects;

β-carotene encapsulated can improve the bioavailability during the human digestion because the particles protects it's against unfavorable conditions in certain part of the digestive tract (e.g., stomach) and releases the min targeted area (e.g., intestine) [18,19].

Different encapsulation techniques and wall materials have been used to *β*-carotene and they have been showed different its retention. Although nanoencapsulation is newer technology than microencapsulation, there are many publications that have involved *β*-carotene nanoencapsulation as well. Some nano and microencapsulated *β*-carotene studies are reported bellow.

Bezerra et al., [15] nanoencapsulated Spirulina using yellow passion fruit albedo as encapsulant and used the solvent displacement method. After 60 days of storage at 4 °C, the greatest retention of carotenoids was observed in nano dispersions containing microalgae extract and albedo flour, resulting in 63.25±0.01 and 58.78±0.02% for all-trans-*β*-carotene and zeaxanthin, respectively, and less retention of synthetic *β*-carotene (12.9±0.02%). They discussed that the higher retention of all-trans-*β*-carotene and zeaxanthin could be attributed to the synergistic effect provided by the carotenoid groups present in the microalgae extract;

Using emulsification-diffusion method and poly-caprolactone as encapsulant to *β*-carotene nanoencapsulation, González-Reza et al., [20], showed that the minimum *β*-carotene retention after encapsulation was around 70%, leading to the inference that nanoencapsulation provides properties of heat resistance to antioxidant compounds such as *β*-carotene. According them, nanoencapsulation provides an additional protector effect that impedes the degradation of thermolabile compounds in a thermal process. This effect is attributed to the presence of the membrane film formed around the oily core.

In his study Silva et al., [21] produced *β*-carotene nanoparticles using a high-energy emulsification-evaporation technique and studied the effect of processing variables (homogenization time, shear rate and number of cycles), and evaluated the stability during 21 days of storage. They did not show the *β*-carotene retention in the article but attributed the decrease in the *β*-carotene content to the high surface area of the nanoparticles and the high degree of medium oxygenation occurring during the homogenisation step.

Tan and Nakajima [23] and Yuan et al., [13] nanoencapsulated *β*-carotene by high pressure homogenization method. Tan and Nakajima [23] found that over 12 weeks of storage at 4 °C, the retention of *β*-carotene in the nano dispersions varied from 25.2% to 56%. They reported that the surface area, which was higher in nano dispersions, was a contributing factor to *β*-carotene loss, which is larger than in a *β*-carotene crystalline solution, in addition to the formation of free radicals during the high-pressure homogenization process. Yuan et al., [13] found after 4 weeks of storage at 4 and 25 °C, that the *β*-carotene retention ranged from 75% to 86%. They suggested that the degradation during storage may be a problem for the use of high-pressure homogenization in commercial products.

According to Hejri et al., [23], whom nanoencapsulated *β*-carotene by solvent diffusion method, the retention of *β*-carotene ranged 25.82 % - 97.95% and it was calculated after 1 week of storage in closed containers with fix temperature of 25 ± 3 °C.

Qian et al., [25] investigated the impact of carrier oil composition and physical state on the physical and chemical stability of lipid nanoparticles containing encapsulated *β*-carotene. For this proposal they prepared liquid lipid nanoparticles (LLNs) and solid lipid nanoparticles (SLNs) using hydrogenated palm oil or/ and cocoa butter, using a hot high-pressure homogenization method. They found that fraction of *β*-carotene retention in the suspensions after storage at 30 °C for 8 days was 56.1±0.8% for LLNs and 50.3 ± 1.2% for SLNs. These results suggest that the stability of the *β*-carotene encapsulated was actually worse in lipid nanoparticles that were solid than in those that were liquid. The authors suggested that the *β*-carotene molecules were expelled from the fat crystals formed in the SLN suspension, which increased their concentration at the surface of the lipid nanoparticles.

Despite of microencapsulation, Ferreira et al.,[14] and Jain et al., [26] microencapsulated crude palm oil and *β*-carotene, respectively, using spray drying and coacervation technique, respectively. Ferreira et al., [14] used as encapsulant gum arabic and cassava starch and they did not find statistical difference carotenoid content of crude palm oil before (608.39±32.94µg/g) and after (600.52±16.05µg/g), indicating that the spray drying processing conditions preserved the bioactive compounds. Furthermore, after stored of 5 weeks at 45 °C, the *β*-carotene retention of encapsulated oil was 63.02%. They concluded that compared to other oils, crude palm oil remains an important source of bioactive compounds and has the potential to be applied in the food fortification industry. On the other hand, Jain et al., [26] used as encapsulant casein and gum tragacanth and they evaluated *β*-carotene retention at three levels of temperature (5, 25 and 40 °C) for 3 months. They observed that the particles stored at elevated temperature have revealed maximum discoloration and the smallest retention content when compared to ambient and refrigerated conditions.

Conclusion

In conclusion, encapsulation is a promising technology used to protect and improve the *β*-carotene application in food.

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Different techniques can be used to encapsulate β-carotene and most of them are utilized to improve its stability during storage. In general, the β-carotene retention is around 60-70%, which is interesting since the encapsulation has promoted a real protection of this bioactive compound and this technology can increase the application of these fat-soluble compounds, in the different research fields.

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Conflict of Interest

The authors have declared no conflicts of interest.

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