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Determination of Carotenoid Bioavailability from Palm Oil Microencapsulation

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ABSTRACT

Indonesia is the largest palm oil supplier in the world with a total production value of 20.97 million tons. Palm oil has a high content of carotenoids that act as antioxidants in the body. However, carotenoids and their derivatives have a conjugated structure that is unstable to oxidation and easily damaged. One of the optimal efforts to maintain the stability of carotenoids is by microencapsulation. This study aims to determine the efficiency of the palm oil microencapsulation method in maintaining the carotenoid components in it. The method used in this research is Systematic Literature Review based on Google Scholar, ScienceDirect, and Springer databases with predetermined inclusion criteria. The results showed that all palm oil microencapsulation methods produced good efficiency values and stable physicochemical characteristics of carotenoids even including other micronutrients such as vitamin E, moisture content, fatty acids, etc. which were also classified as stable. Overall, the supercritical carbon dioxide (SEDS) method produced the best quality while the spray drying method is a good choice for commercial microencapsulation. The conclusion of this study is that microencapsulation is able to protect the bioavailability of carotenoids in palm oil in a stable condition with values that are still within the standard range so as to produce better palm oil products as food ingredients for further use in a food product.

Keywords: Carotenoid, microencapsulation, palm oil

INTRODUCTION

The level of vegetable oil consumption in the world in 2020/2021 reached 209.14 million metric tons with palm oil as the largest supporter of consumption figures, reaching 73.22 million metric tons (GAPKI 2021). Palm oil is produced from oil palm plantations, one of which is Indonesia, which is the largest palm oil supplier in the world with a total production figure of 45.5 million metric tons in the 2022/2023 period (United State Department of Agriculture 2023). This is in line with the high level of palm oil consumption in Indonesia. According to the Indonesian Palm Oil Association's 2023 report, Indonesia's total crude palm oil (CPO) consumption was 20.97 million tons in 2022, an increase of 13.82% from 2021 (Canossa *et al.* 2020). Palm oil contains complex nutrients, such as beta carotene and provitamin A that act as antioxidants in

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the body, either alone or together with other carotenoid compounds such as lycopene, lutein, and others. Palm oil's beta carotene content is proven to be higher than carrots, tomatoes, papaya, and spinach leaves. (Dong *et al.* 2017). In addition to beta carotene, the fat content of palm oil is also good balanced with 50% saturated fat, 39% monounsaturated fat (MUFA), and 11% polyunsaturated fat (PUFA) (Marliyati *et al.* 2021). Cooking oil is mostly used by people as the main ingredient for frying. According to Zhang *et al.* (2020), during the frying process two things will occur, namely cooking and dehydration. Cooking will trigger several heat-induced chemical reactions such as starch gelatinization, protein denaturation, Maillard reaction and caramelization, while dehydration occurs because the frying process occurs at temperatures above 100 °C and water evaporation occurs. This promotes the destruction of carotenoids contained in the oil. Carotenoids and their derivatives have a conjugated structure making them unstable to oxidation and easily degraded when exposed to light, oxygen, acids, and heat during food processing and storage. (Aryayustama *et al.* 2018).

One of the optimal efforts to maintain the carotenoid content in palm oil is the encapsulation process. Encapsulation aims to protect environmentally sensitive substances, protect organoleptic properties such as colour, taste, and odor as well as maintain bioactive content and extend shelf life (Agustin and Wibowo 2023). In addition, several studies have reported that encapsulation is effective in preserving nutrients during processing and increasing the bioavailability of nutrients during digestion (Ananda *et al.* 2023). Research on the application of microencapsulation to palm oil has often been carried out with a variety of different methods such as Spray drying, complex coacervation, Foam-Mat Drying, Solids Content, and supercritical carbon dioxide (SEDS). This study aims to analyse each method of microencapsulation of palm oil by comparing aspects of efficiency and quality of the products produced.

MATERIAL AND METHODS

This research uses a systematic literature review method with keywords related to the research topic, namely "microencapsulation", "palm oil", and "carotenoids" within the last 10 years. This search was conducted on various databases, namely ScienceDirect and Google Scholar. The articles selected were those that fell within the inclusion criteria, which included articles with experimental study designs, full-text and accessible articles, and articles that focused on the effectiveness of palm oil microencapsulation or the stability of the concentration of bioactive components in it. All selected articles were then compiled and analysed comprehensively. The article selection process can be seen in the figure below.

RESULT AND DISCUSSION

The success of microencapsulation is influenced by the suitability of the method and the material to be encapsulated. Based on Table 1, there are 7 experimental studies on the application of microencapsulation to palm oil with several different encapsulation methods, namely spray drying, complex coacervation, foam-mat drying, solids content, extrusion, and supercritical carbon dioxide (SEDS). Each study had different types of binders such as maltodextrin (MD), emulsifying starches, and Gum Arabic (GA). Spray drying is the most commonly used method because it has a simple procedure, economical, and produces microcapsules with effective quality and stability to protect the core material (Poshadri 2010). However, this method has the disadvantage that the operation process requires high temperatures to produce microencapsulated products, which can cause damage to food ingredients. Research (Carmona *et al.* 2018) reported the results of palm oil

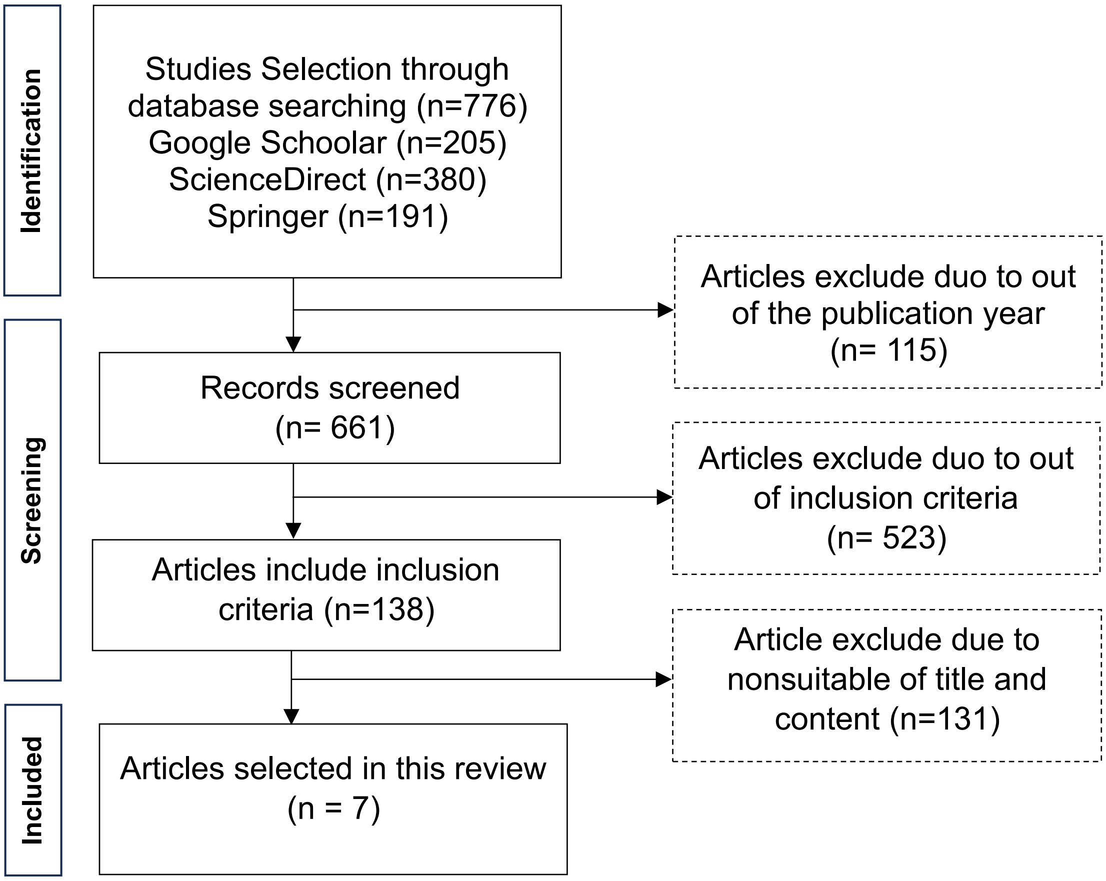

Figure 1 Flow chart selection process of the studies.

Table 1 Article research about effectiveness of carotenoid stability in palm oil microencapsulation.

No	Authors	Wall Material	Microencapsulation Method	Result	Conclusion
1	(Rutz *et al.* 2017)	Chitosan/xaanthan and chitosan/pectin	Complex coacervation	Encapsulation efficiency (EE) of carotenoids. Lyophilization (52.20% (pectin) and 62.41% (xanthan)) and Atomization (22.25% (pectin) and 32.67 (xanthan)). Bioavailability (lyophilization) pectin 39% and Xanthan 50.1%.	The lyophilization drying technique provides more efficient results compared to atomization with a fairly good level of bioavailability
2	(Saputri & Ngatirah 2019)	Na-alginat, pati sagu, *carboxyl methyl cellulose,* and chitason	Foam-mat drying	Sago starch dressing type gave the best results with a moisture content of 2.08%, free fatty acid of 0.63%, peroxide number of 23.61 meq/kg, carotenoid content of 131.61 ppm, encapsulated oil content of 53.62%, solubility of 57.03%, and munshell color of 91 (intense yellow).	Sago dressing can provide resistance to carotenoids, free fatty acids, etc.
3	(Ananda *et al.* 2023)	Carragenan	Supercritical carbon dioxide	Encapsulation effectiveness was 99.42% (fermented) and 99.02% (unfermented). In addition, bioavailability 96.11% (unfermented RPO) 99.69% (fermented RPO).	Microencapsulation is effective in both fermented and unfermented RPO with good bioavailability.
4	(Carmona *et al.* 2018)	Gum arabic	Solids content and spray-drying	The microencapsulation efficiency was 61.37–85.61% and the carotenoid content after microencapsulation was 2775.79 µg/g oil from the total content of 2910.55 µg/g oil.	Microencapsulation as a protection and preservation solution is proven to be effective but is affected by the suitability of the solids content, feed flow rate, and inlet air temperature.

5	(Lee *et al.* 2018)	Sodium caseinate, maltodextrin, and soy lecithin	Solution enhanced-dispersion by supercritical carbon dioxide (SEDS)	The best environmental conditions were at 125 bar pressure and 50°C with carotenoid efficiency retention of 82.7±12.2%; vitamin E efficiency retention of 94.3±8.0%; particle number of 5.81±2.8μm; moisture content of 3.1–4.5%; and microencapsulation efficiency of 92.1±4.3%.	Supercritical carbon dioxide (SEDS) is able to maintain fairly good physicochemistry
6	(Lee *et al.* 2020)	Sodium caseinate, maltodextrin, and soy lecithin	Supercritical carbon dioxide (SEDS) and spray drying (SD)	Supercritical carbon dioxide (SEDS) microencapsulation had the highest stability (9.8-26.5), followed by SD-M (9.2-34.9) and RPO (5.7-56.7); activation energies (Ea,kJ/mol) and absolute average relative deviations (AARDs,%) showed SEDS < SD < RPO. Bioactive concentrations. SEDS-M protects lipid oxidation and vitamin E and SD protects carotenoids.	Supercritical carbon dioxide (SEDS) is better than spray drying (SD) insignificantly.
7	(Ferreira *et al.* 2016)	Cassava starch, gum arabic, and whey protein concentrate (derived from milk)	Spray drying	After encapsulation, the average carotenoid content of crude palm oil was 600.52±16.05 μg/g from 608.39±32.94 μg/g; peroxide number was 11.16±0.00 meq/kg from 3.56±0.19 meq/kg; antioxidant activity was 29.25±1.13% from 56.83±2.49%; and fatty acid profile was 40.89±0.15 from 40.57±0.26.	The spray drying method with cassava starch and gum arabic as coating materials resulted in carotenoid stability that still remained within the standard limits, including in terms of encapsulation efficiency, carotenoids, fatty acids, peroxide number, and antioxidant activity.

Note: One of the most limiting factors of this data is on the different palm oil source used in each study.

encapsulation using the spray drying method with Gum Arabic (GA) dressing, obtained the lowest microencapsulation efficiency of 61.37% and the highest value of 85.61% with a fairly good level of bioavailability (2775.79 μg / 2910.55 μg total carotenoids). These results are influenced by several things, namely having a significant positive relationship with solids, feed flow, and inlet air temperature.

Research by Ferreira *et al.* (2016) reported the results of palm oil micro-encapsulation by spray drying method in the range of 28.66 to 56.96% with efficiency values from 92.77 to 97.89%. The highest efficiency value was obtained with gum arabic (80%) combined with whey protein concentrate (20%). However, the encapsulation process decreased the carotenoid content in palm oil from 608.39 ± 32.94 μg/g to 600.52 ± 16.05 μg/g (not significant). This is because the spray-dryer heat could have promoted isomeri-zation of trans carotenoids to their less com moncis forms.

Research by Rutz *et al.* (2017) comparing the encapsulation process with atomization (spray drying) and lyophili-zation, the results obtained by the lyophili-zation process have better effectiveness although not significant. In the bioavailability test, the lyophilization method has a value of 39% (pectin dressing) and 50.1% (xanthan dressing) while in atomization microencapsulation no similar measurements were made. This study explicitly states that the lyophilization method is better than atomization or similar to spray drying and proves that micro-encapsulation is able to increase the bioavailability of carotenoids.

The development of microencap-sulation methods continues to occur, one of the latest methods that has proven effective is supercritical carbon dioxide (SEDS). Lee *et al.* (2020) show that super-critical carbon dioxide (SEDS) is more stable than spray drying (SD), which may be due to differences in (i) the encapsula-tion process, (ii) initial surface oil content, and (iii) microcapsule size and morphology. SEDS had the highest oxidative stability ($p<0.05$) during storage (PV: 2.7–9.3 meq/kg), followed by SD (PV: 2.8-10.6 meq/kg) and RPO (PV: 2.6–14.0 meq/kg). Previously, Lee *et al.* (2018) also examined the single effectiveness of supercritical carbon dioxide (SEDS) and obtained the results that the Microencapsulation of red palm oil (o/w) with the SEDS method obtained the best properties at a pressure of 125 bar and a temperature of 50°C, namely with a carotenoid efficiency retention value of 82.7 ± 12.2% with an efficiency value reaching 92.1 ± 4.3%. The study also reported that the SEDS method compared to SD has less oil content, higher microencapsulation value and particle number, and more stable carotenoid bioavailability value.

Research on the effectiveness of supercritical carbon dioxide was also conducted by Ananda *et al.* (2023) which stated that the microencapsulation efficiency reached 99.42% and the unfermented 99.02%. This is also in line with the level of bioavailability of microencapsulated 96.11% in unfermented RPO and 99.69% in fermented RPO. The high rate was influenced by the solvent carrageenan with a high solubility level that covers the core material (palm oil) so as to provide comprehensive protection. Based on this description, the supercritical carbon dioxide method has the most optimal value both in terms of stability and bioavailability of carotenoids produced but the spray drying method has a lower value but is still classified as an effective standard for the microencapsulation process. In addition to the quality aspects of the procedure and the cost required, the spray drying method has a higher efficiency so it is very suitable when used in commercial products.

CONCLUSION

Palm oil is the world's most favourite source of vegetable oil. Palm oil has a high content of carotenoids. However, oil as a high temperature processing material is very susceptible to damage. Microencapsulation is an effort to improve the physicochemical quality of food products. There are several methods that can be used, the supercritical carbon dioxide method has the best effectiveness compared to other methods. However, spray drying can be used as an alternative in commercial foods because it has better efficiency.

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