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Encapsulation of Turmeric Extract and Rice Bran Oil in Alginate Hydrogel microcapsules

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ABSTRACT

Turmeric extract (TAE) and rice bran oil (RBO) have grown in popularity among consumers in recent years due to their wide spectrum of biological activity. The main bioactive component of turmeric, curcumin, has demonstrated promise as a possible anti-carcinogenic agent. Meanwhile, RBO, rich in γ-oryzanol and other phytosterols, has demonstrated efficacy in enhancing immune system function, thereby shielding the body against diseases. The objective of this study was to obtain and characterize alginate microcapsules containing turmeric aqueous extract and rice bran oil and to evaluate the effects of freeze drying and air drying on curcumin, γ-Oryzanol, total phenol contents, and DPPH of TAE and RBO microcapsules. Results show that non-dried (ND) and freeze -dried (FD) recorded 5.97 and 5.69 mg/g for curcumin content and 0.156 and 0.150% for γ-Oryzanol content, respectively. On the other hand, air-dried (AD) microcapsules were significantly lower than ND and FD microcapsules reaching 4.32 mg/g for curcumin content and 0.116 % for γ-Oryzanol content. Also, sensory evaluation showed that non-dried and freeze-dried microcapsules were significantly accepted.

1. Introduction

There is a growing demand for novel, healthful foods that are high in fiber, low in calories, and enriched with nutrients (Wang et al., 2018). The sports nutrition product category is experiencing tremendous growth as a result of individuals becoming more health-conscious, leading more active lifestyles, and realizing the advantages of these products (Arenas-Jal et al., 2020a). Drinks, snacks, gels, chews, bars, and shots are examples of portable and convenient formats that are gaining popularity. These formats are also being redefined to include ingredients that are intended to support optimal performance (Maughan and Shirreffs 2012). This results in restricting the use of synthetic food additives and preservatives in favor of naturally occurring bioactive compounds, such as those found in fruits, vegetables, and other plant-based sources. Food producers are making an effort to cut back on or eliminate the use of synthetic preservatives due to the trend towards "healthy eating" and environmental concerns. They are also becoming interested in technologies that stabilize bioactive substances so that they may modify their physical properties while retaining their functional qualities during processing and storage (Patrignani et al., 2020). Functional foods are modified foods that claim to improve health or well-being by providing benefits above their basic nutritional value. Beverages, cereals and breads that have been fortified or enriched with beneficial food sources, like herbs that contain antioxidants, minerals, vitamins, probiotics, prebiotics, enzymes, and/or phytonutrients, can all be considered functional foods. In addition to their nutritional advantages, functional foods are useful against several health issues because of their antibacterial, anti-inflammatory, and anti-carcinogenic characteristics. Numerous food products with functional properties are being created and are currently having a significant market presence (Hanafi et al., 2017). Food-sourced bioactive ingredients generally represent components of natural foods that exhibit specific physiological functions, among which are polyphenols, vitamins, bioactive polysaccharides, polyunsaturated fatty acids, bioactive peptides and minerals, which have been proven to have numerous beneficial impacts on human Health (Bao et al., 2019).

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Curcuma longa L.'s rhizomes are the source of the spice turmeric, which has been used for ages in a variety of traditional medical practices and cuisines. It is a common component in culinary traditions all across the world because of its distinctive flavor and vivid yellow color. Turmeric has a long history and cultural significance beyond its culinary uses, especially in South Asia (Prasad et al., 2021).

The main bioactive component of turmeric, curcumin, has demonstrated promise as a possible anti-cancer agent. It operates through various techniques, such as preventing the growth of tumors, causing cancer cells to undergo programmed cell death, and preventing the development of new blood vessels that support the growth of tumors. It has been proven to reduce blood glucose, increase insulin sensitivity, and inhibit diabetes-related inflammation (Bozkurt et al., 2022). The potential advantages of curcumin for digestive disorders, immunological function, liver health, and cardiovascular health have all been investigated (De Filippis et al., 2020). In the food sector, curcumin has applications as a flavoring, preservative, and yellowish colorant agent. It is easily oxidized and light-damaged (Hamad et al., 2023).

Rice (*Oryza sativa* L.) is a plant that belongs to the family Poaceae. Following wheat and maize, it is one of the three main food crops grown worldwide and constitutes the majority of the diet of the world's population. Rice world production in 2022 is pegged at 519.5 million tons (FAO, 2022). Rich in lipids, proteins, and carbohydrates, rice bran is an insufficiently utilized by-product of rice milling that represents about 5%–10% of the grain (Spaggiari et al., 2020). Between 12% and 23% of rice bran is lipid, which produces rice-bran oil (RBO) when extracted including a variety of bio-active phytochemicals such as oryzanol, tocotrienol, phytosterol, polycosanol, squalene, phytic acid and ferulic acid (Saikia and Deka, 2011). These phytochemicals display a wide range of biological activities by operating as antioxidant, anti-diabetic, anti-inflammatory, anti-hyperlipidaemic, and anti-carcinogenic agents (Garofalo et al., 2021). It has been proven that including 20 g of rice bran oil spread in a regular diet will effectively reduce serum cholesterol levels (Lai et al., 2012). Because of its high content of γ-oryzanol, a potent antioxidant and anti-free radical that lowers total plasma cholesterol, improves high-density lipoprotein cholesterol levels and inhibits platelet aggregation, RBO is a product of great value with distinct health benefits and is known as the heart-friendly oil (Bumrungpert et al., 2019; Zubair et al., 2012). Because of its special characteristics, RBO is a great ingredient for an extensive variety of uses, including the culinary, pharmaceutical, cosmetic, and nutraceutical sectors (Lai et al., 2021). Rich in γ-oryzanol and other phytosterols, RBO has demonstrated efficacy in enhancing immune system function, thereby shielding the body against diseases. RBO is a component of sports supplements used by bodybuilders and athletes for muscle development (Nayik et al., 2015). As a result of oxidative deterioration, RBO must be protected from the damaging impacts of oxygen, light, and temperature to prevent alterations in its nutritional and organoleptic characteristics throughout storage and process operation (Bakry et al., 2016). Microencapsulation technology has become one of the most interesting techniques for preserving bioactive components, including vitamins, volatile chemicals, essential oils, pigments, and more (Hoyos-Leyva et al., 2019).

Microencapsulation is the technique of producing and shielding bioactive substances from environmental elements, such as light, oxygen, temperature, and other external factors, or from engaging in interactions with other food system ingredients through the use of appropriate matrices that enhance the stability, flavor, and color of the compounds (Sun et al., 2020). Furthermore, it can conceal the distinct taste and smell of oil, which expands the use of oil microcapsules in a variety of food items (Jeyakumari et al., 2016). By providing unique health benefits and desired functionality to food products, encapsulation can improve its application in the food sector. It can solve global micronutrient deficits (Chew et al., 2019).

Oil is stabilized and made easier to work with by microencapsulation, which enables it to be utilized

in the manufacturing of numerous food products (Arenas-Jal et al., 2020b).

Microencapsulation refers to the process of coating or encapsulating a particular material or combination of materials within the shell of a specific material or system. Encapsulated material is referred to as active, encapsulated, or core. A mixture of solid, liquid, and gaseous forms can be used as the core material, or it can be one single substance. The enclosing polymer is called a shell, wall, or coating (Bakry et al., 2016; Arenas-Jal et al., 2020b). Depending on the microencapsulation technology utilized, microcapsules can range in size from 1 to 1000 μm (Ozkan et al., 2019).

A recent study by Global Market Insights (2023) estimated that the food encapsulation market would grow at an annual compound growth rate of 6.5% between 2023 and 2032, with a value estimated at USD 41 billion in 2022. The success of the procedure depends on the selection of encapsulating materials, as they affect the encapsulation efficiency (Kang et al., 2019). The most often used encapsulating substance in the food industry is polysaccharides (Nedovic et al., 2011). Consisting of D-mannuronate and L-guluronate, alginate is an anionic polysaccharide obtained from seaweed. It forms hydrogels when the negatively charged uronic acid groups bind with cations like calcium (Ca^{2+}) by ionic complexation (Beaumont et al., 2021). Alginate hydrogels are ideal for encasing bioactive food ingredients because of their many exceptional qualities, such as hydrophilicity, biodegradability, biocompatibility, and non-toxicity (Li et al., 2019). Moreover, alginate hydrogels are more preferred for encapsulating sensitive active components since the technique is flexible and fairly simple, and suitable alginate hydrogels form under mild conditions (Bao et al., 2019). Research has demonstrated the health benefits of alginate as an important source of dietary fiber in reducing glucose and cholesterol uptake, as well as its advantages in cardiovascular and gastrointestinal diseases (Tabassum and Khan, 2020). The main objective of this investigation was to obtain and characterize alginate microcapsules containing turmeric aqueous extract and rice bran oil and to evaluate the effect of freeze drying and air drying on the obtained microcapsules.

2. Materials and Methods

Materials

Sodium alginate and Calcium chloride were purchased from S D Fine Chem Ltd, Mumbai, India, rice bran oil was purchased from Thai Edible Oil Co., Ltd., Bangkok, Thailand. A commercial product of Curcuma longa L. powder was used and organic orange juice was obtained from local market in Giza, Egypt. All used chemicals, solvents, DPPH (2,2-diphenyl-1-picrylhydrazyl), Gallic acid and Folin-Ciocalteu were purchased from Sigma-Aldrich (St. Louis, Missouri, USA.)

Methods

Encapsulation of turmeric aqueous extract and rice bran oil in alginate hydrogel microcapsules

Turmeric aqueous extract preparation

The (Cortez et al., 2020) method to prepare an aqueous extract of turmeric (TAE) was used with minor modifications by heating turmeric powder with water (1:10) at a constant temperature of 100 ºC for 5 min. The extract obtained was filtered through Whatman No. 1 filter paper and analyzed for curcumin content, total phenolic compounds, and antioxidant activity.

Encapsulation process

A solution of sodium alginate 2% w/v was prepared by dispersing, at room temperature, the sodium alginate powder in the previous turmeric aqueous extract and mixing gently by using the magnetic stirrer at 1000 rpm till dissolved. After that, rice bran oil (RBO) (10 g) was dripped gradually into the solution, and for 45 minutes, the mixture was stirred at 1000 rpm. To create a proper emulsion, the oil was slowly added to the alginate solution in this phase. A solution of calcium chloride 2% w/v was prepared by dissolving the salt in deionized water. To carry out the encapsulation, the sodium alginate, turmeric aqueous extract, and RBO mixture was dropped manually into the calcium chloride solution using a 5 mL pipette to form the alginate beads from a height of 10 cm, where good

droplet penetration into the liquid was noticed (Pascual-Pineda et al., 2014).

The resultant microcapsules were allowed to solidify for twenty minutes in the $CaCl_2$ solution, and then they were washed twice with distilled water after being extracted from the solution using a filter. Next, the microcapsules underwent drying.

Freeze drying

The freeze-drying process was carried out using a freeze-dryer (Labconco freeze dryer, FreeZone, 12L, U.S.A.), and it was frozen at −50 ºC for 48 h. The chamber pressure was kept below 0.1 mbar during the drying process. When the freeze-drying process was complete, the dried samples were kept at 25 °C at the same pressure for 2 hours and then stored in tightly closed vials.

Air drying

The microcapsules were allowed to dry for ten hours at room temperature (25 °C) on a lab bench. The dried samples were kept in firmly sealed vials after the drying process was complete.

Encapsulation efficiency

The encapsulation efficiency (EE) is the percentage ratio between the amount of oil loaded on the microcapsule surface and the initial amount used to make the formulation. The encapsulation efficiency (EE %) was calculated by the following equation (Gupta et al., 2015) :

$$EE\ \% = \frac{TO - SO}{TO}$$

Where TO is the total oil content and SO is the surface oil content.

SO is determined by mixing microcapsules (2 g) in 15 mL hexane, which was shaken for 2 min at room temperature to extract surface oil. The solvent was filtered through Whatman No.1 filter paper, and then, the powder was collected.

Encapsulation yield

The encapsulation yield (EY%) of microcapsules was defined as the ratio of the weight of microcapsules collected to the mass of initial substances, including the turmeric extract, alginate and RBO (Fang and Bhandari, 2011).

Curcumin content

HPLC analysis was carried out using an Agilent 1260 series. For curcumin the column used was Agilent C18 (4.6 mm x250 mm i.d., 5 µm). The mobile phase was ACN: 2% Acetic Acid (50:50, v/v) and the flow rate was 2 mL/min. The injection volume was 5µl for each of the sample solutions. The MWD was adjusted at 425nm. The column temperature was maintained at 40°C (Wichitnithad et al., 2009).

γ-Oryzanol content determination

Samples of precisely measured amounts (about 10 mg each) were dissolved in hexane and made up to 10 mL and thoroughly mixed. The O.D. was read in a 1cm cell at 314 nm in a Shimadzu UV-240 double-beam recording spectrophotometer **(**Krishna et al., 2006**)**. The γ-Oryzanol content in the oil was calculated using the formula:

$$\gamma - Oryzanol\ \% = \frac{O.D\ of\ hexane\ solution}{Weight\ of\ oil\ (g)} \times \frac{100}{358.9}$$

Where 358.9 is the specific extinction coefficient of γ-Oryzanol.

Total phenols content (TPC)

Total phenol content was measured using the Folin-Ciocalteu reagent as described by (Singleton et al., 1999). A standard curve was prepared to express the results as mg gallic acid equivalents (GAE)/100g sample.

Determination of antioxidant activity

Free radical scavenging activity was done according to the technique described by **(**Hung and Morita 2008) using 1,1-diphenyl2-picrylhydrazyl (DPPH).

Scanning electron microscopy (SEM)

Morphological analysis of the microcapsules was performed using a scanning electron microscope (Quanta FEG 250, Thermo Fisher Scientific (FEI), United States of America). The samples were fixed with metal support and a carbon double-surface band, covered by a fine gold layer, and subsequently visualized under 100–1500 magnification at an excitation voltage of 20 kV.

Sensory evaluation

Organic orange juice (200ml) with the addition of 100 g of non-dried microcapsules, the equivalent of this weight as air-dried microcapsules or freeze-dried microcapsules (15g) were added, and control orange juices were served in randomly numbered plastic cups on a tray with a cup of water.

Ten members of Food Technology Research Institute, Agricultural Research Center, Giza, Egypt evaluated the orange juice samples for taste, color, texture, flavor and overall palatability. A nine-point hedonic scale test was used as described by (Lawless and Heymann 1998), on a specific scale of 9, where 1 indicated extreme dislike and 9 indicated extreme like.

Statistical analysis

The obtained results were statistically analyzed using the CoStat program version 6.4 (Costat 6.4, CoHort software). The P-value of less than 0.05 was considered significant (Steel and Torrie, 1980).

3. Results and Discussion

Curcumin, γ-Oryzanol, total phenol contents and DPPH of TAE and RBO

Curcumin, γ-Oryzanol, total phenol contents (TPC) and DPPH of TAE and RBO are presented in Table 1. Curcumin, a phenolic compound, has become more popular in recent years due to its wide spectrum of biological activity. It could be observed that the TAE content of curcumin recorded a lower value, reaching 6.17 mg/g, than the content reported by (Cortez et al., 2020) who studied the effect of different cooking methods on the nutritional quality of turmeric and found that boiled turmeric in water recorded 7.70 mg/g of curcumin content. The curcumin content varies under the combined effects of cultivar-specific traits, weather conditions, and agricultural practices (Hwang et al., 2016).

γ-Oryzanol acts as a powerful antioxidant that can lower blood lipid levels and reduce the risk of coronary heart disease (Bumrungpert et al., 2019).

Data presented in Table 1. showed that RBO contained 1.84% γ-Oryzanol, which is in the range reported by (Wongwaiwech et al., 2023 and Lloyd et al., 2000), who reported that the γ-Oryzanol content of RBO ranged from 0.74 to 2.9%.

Table 1. Curcumin, γ-Oryzanol, total phenols contents and DPPH of TAE and RBO

	Curcumin mg/g	γ-Oryzanol %	TPC mgGAE/100g	DPPH%
TAE	6.17	---	480.23	62.21
RBO	---	1.84	589.75	70.96

TAE: turmeric aqueous extract-RBO: rice bran oil

Plant phenolic compounds play a major role as free radical scavengers and are essential components that contribute to functional quality, color, and flavor (Tanvir et al., 2015). From the results in Table 1., it could be noticed that TPC reached 480.23 mg GAE/100g for turmeric aqueous extract. This result is in accordance with the results obtained by (Nisar et al., 2015), who investigated the total phenols of turmeric using different solvents and found that TPC for the aqueous extract recorded 496.76 mg GAE/100g. Meanwhile, the RBO content of total phenol content recorded 589.75 mg GAE/100g. Previous research illustrated that the total phenol content of the RBO samples ranged between 400.39 and 663.00 mg GAE/100g (Wongwaiwech et al., 2023; Mingyai et al., 2017). The DPPH-free radical-scavenging activity of the aqueous extracts of turmeric and rice bran oil was investigated to determine their antioxidant properties. Data are tabulated in Table 1. Turmeric aqueous extract recorded 62.21% for DPPH, which is higher than the percentage reported by (Array et al., 2019), who studied the effect of different extraction solvents on the antioxidant activity of turmeric grown in Cameroon and found that aqueous extracts DPPH ranged from 15 to 60%. On the other hand, DPPH for RBO was

recorded at 70.96%, which was in the range reported by (Soares et al., 2018), who stated that the RBO extracts DPPH values ranged from 69.3 to 72.4%.

Effect of air drying and freeze drying on encapsulation efficiency and encapsulation yield of TAE and RBO microcapsules

Encapsulation efficiency is considered the most crucial factor because it determines whether a particular functionality of the encapsulated component is being delivered into the food matrix or not (Choudhury et al., 2021). The encapsulation efficiency and encapsulation yield of the non-dried (ND), air-dried (AD), and freeze-dried microcapsules (FD) are shown in Table 2.

Encapsulation efficiency for ND and FD microcapsules recorded 96 and 94%, respectively, which were significantly higher than AD microcapsules, which reached 67%. These results are in agreement with (Rutz et al., 2017), who stated that EE% was higher for the freeze-dried microcapsules with palm oil, containing high carotenoid content, while comparing drying methods.

Table 2. Effect of freeze drying and air drying on encapsulation efficiency (EE%) and encapsulation yield (EY%) of TAE and RBO microcapsules

	EE%	EY%
ND	96[a]	95.00[a]
AD	67[c]	69.86[c]
FD	94[b]	93.15[b]
LSD	0.998	0.599

Different letters indicate significant differences at ($P<0.05$). ND: non-dried, AD: air-dried and FD: freeze-dried microcapsules.

From an economic standpoint, the encapsulation yield (EY%) is significant in any encapsulation procedure due to the expense of the polymers and active principles utilized (Ale et al., 2015). The encapsulation yield of ND was recorded at 95.0%, which is in agreement with (Azad et al., 2020), who stated that the percentage of yield of alginate microcapsules with black seed oil was 94.87%. The loss of some emulsion during the electrospray process through the needle is the likely cause of the bead loss.

Meanwhile, the encapsulation yields of AD and FD reached 69.68 and 93.15%, respectively. (Rutz et al., 2017) demonstrated that freeze drying is the most suitable drying method because it provides a higher yield and leads to lower carotenoid losses during the encapsulation process.

Effect of air drying and freeze drying on curcumin, γ-Oryzanol, total phenol contents, and DPPH of TAE and RBO microcapsules

Results in Table 3. showed the effect of air drying and freeze drying on curcumin, γ-Oryzanol, total phenol contents, and DPPH of TAE and RBO microcapsules. It could be noticed that the freeze drying process maintained the aforementioned chemical analysis, where ND and FD recorded 5.97 and 5.69 mg/g for curcumin content, 0.156 and 0.150 % for γ-Oryzanol content, 456.67 and 440.88 mg GAE/100 g for total phenol content, and 62.05 and 60.56 % for DPPH, respectively. On the other hand, air-dried microcapsules were significantly lower than ND and FD microcapsules, reaching 4.32 mg/g for curcumin content, 0.16% for γ-Oryzanol content, 323.98 mg GAE/100 g for total phenol content, and 44.02% DPPH. These results are in agreement with (Pashazadeh et al., 2021), who demonstrated that, when compared to other drying techniques, freeze-drying was the most effective way to dry microcapsules, providing the highest values of polyphenols and DPPH. Additionally, (Guo et al., 2020) stated that freeze drying would be a preferable option for the microencapsulation of sensitive compounds like curcumin. The reasoning for this is that, in comparison to other drying techniques, freeze drying uses milder processing conditions (low temperatures and absence of oxygen).

Table 3. Effect of air drying and freeze drying on curcumin, γ-Oryzanol, total phenols contents and DPPH of TAE and RBO microcapsules

	Curcumin mg/g	γ -Oryzanol%	Total phenols mg GAE/100g	DPPH%
ND	5.97[a]	0.156[a]	456.67[a]	62.05[a]
AD	4.32[b]	0.116[c]	323.98[c]	44.02[c]
FD	5.69[a]	0.150[b]	440.88[b]	60.56[b]
LSD	0.282	0.002	1.532	0.319

Different letters indicate significant differences at (P<0.05).
ND: non-dried, AD: air dried and FD: freeze dried microcapsules

Scanning electron microscopy

The morphology of air- and freeze-dried microcapsules has been studied using scanning electron microscopy. The micrographs of the air-dried microcapsules in Figs. 1a and 1b showed the absence of an ideal spherical shape; the surface of the capsules appears extremely wrinkled and is accompanied by an excessive number of pores or channels. This wrinkled surface can occur due to the drying process. Water loss during drying can empty the area previously filled with water, causing the surface to wrinkle. Several lumps were found due to the irregular pores scattered on the capsules becoming oil traps. These results are in agreement with (Azad et al., 2020 and Soliman et al., 2013), who stated that the formation of lumps is caused by oil droplet deposition towards the outside of the capsules, which results in the plasticization of the capsule structures. The effect of freeze-drying on the exterior structure of the produced microcapsules is depicted in Figs. 1c and 1d. Sublimation of water from the hydrogel matrix resulted in the irregular shape of microcapsules. It appears that freeze-drying of microcapsules resulted in the development of a porous surface structure and cracks because of the increase in water volume during crystallization. This is in accordance with (Kokina et al., 2019), who studied the characterization, antioxidant, and antibacterial activity of lavender, tea tree, bergamot, and peppermint essential oils encapsulated in alginate followed by freeze-drying.

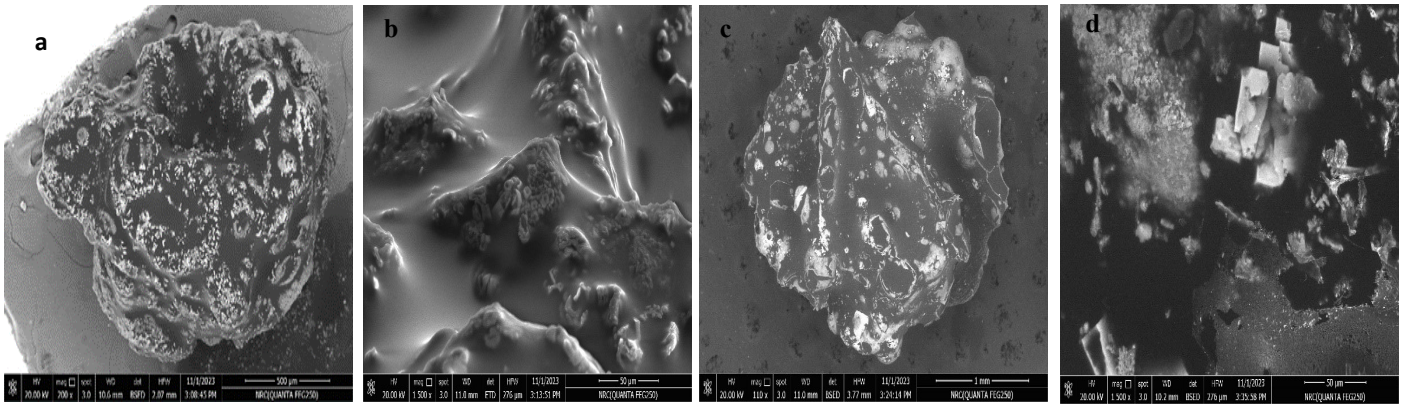

Figure 1. Scanning electron microscope (SEM) of a,b (air-dried TAE and RBO microcapsules) and d,c (freeze-dried TAE and RBO microcapsules)

Sensory evaluation

Sensory characteristics (color, taste, texture, flavor, and palatability) of fresh orange juice (OJ), fresh orange juice containing ND (OJN), fresh orange juice containing AD (OJA), and fresh orange juice containing FD (OJF) were evaluated as shown in Table 4.

Table 4. Sensory evaluation of orange juice with TAE and RBO microcapsules

	Color	Taste	Texture	Flavor	Palatability
OJ	9.0^{a}	9.0^{a}	9.0^{a}	9.0^{a}	9.0^{a}
OJN	8.5^{b}	8.3^{b}	8.0^{b}	8.0^{b}	8.0^{b}
OJA	7.0^{c}	6.0^{c}	5.5^{d}	6.0^{c}	6.0^{c}
OJF	8.4^{b}	8.2^{b}	7.5^{c}	8.0^{b}	7.8^{b}
LSD	0.133	0.230	0.282	0.231	0.282

Different letters indicate significant differences at ($P<0.05$).
OJ: fresh orange juice, OJN: fresh orange juice containing ND, OJA: fresh orange juice containing AD, OJF: fresh orange juice containing FD

Results recorded in Table 4. illustrated that fresh orange juice was significantly the best in sensory quality characteristics compared to all samples. It could be observed that orange juice samples with added microcapsules were acceptable for panelists. (Barroso et al., 2014) stated that all of the quality scores from the sensory evaluation were in the mid-range or higher, suggesting that the dairy drink fortified with flaxseed oil microcapsules was suitable. From data in Table 4. it could be noticed that the OJN and OJF had no significant difference in color, taste, flavor and palatability but had significant differences in texture which is in agreement with (Stojanovic et al., 2012) who found that the texture of the freeze-dried alginate beads was spongy which was expected from the freeze-drying procedure. Meanwhile, OJA recorded the lowest sensory scores. (Krasaekoopt and Kitsawad 2010) found that a significant portion of customers accepted orange and grape juices fortified with probiotic microcapsules, even though this fortification altered the textural features of the products by making them harder to swallow, containing more particles, and making them more turbid. Fruit juice's flavor, nutritional value and health advantages attracted customers. Fish oil has also been researched as a means of fortifying juices with fatty acids; this method increases turbidity without impairing the juice's sensory appeal (Habibi et al., 2017).

4. Conclusion

For the microencapsulation of substances such as curcumin and γ-Oryzanol, freeze drying or without drying would be a better option than air drying. Non-dried and freeze-dried microcapsules were significantly accepted based on physico-chemical and sensory evaluation.

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