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Storage stability and sensory evaluation of tocotrienol-rich-fraction-fortified mayonnaise

Teow, S. J., Choy, H. W., Khor, Y. P., Tan, T. B., Mat Yusoff, M., Gholivand, S. and *Tan, C. P.

Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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Abstract

Tocotrienol, a well-known antioxidant, was encapsulated within microcapsule for application in mayonnaise to determine the storage stability and sensory evaluation. Tocotrienol-rich fraction (TRF) nanoemulsion was first prepared by treated pea protein isolate-flaxseed gum complex, which was then spray dried into microcapsule using maltodextrin-starch sodium octenyl succinate. The present work aimed to determine the physico-chemical, oxidative, and sensory properties of TRF-fortified mayonnaises. Firstly, the control (C-Mayo) and TRF-fortified mayonnaise produced from microcapsule (M-mayo) and bulk oil (O-mayo) were stored at 4°C for four weeks. M-mayo was stable against storage due to low increments of lightness (1.19%), redness (7.50%), yellowness (9.11%), firmness (44.82%), consistency (63.22%), and viscosity (21.29%) as compared to C-mayo and O-mayo. In week 4, M-mayo showed a significantly lower peroxide value (2.66 mq/kg) compared to O-mayo (8.62 mq/kg). After storage, the degradation of tocopherol and tocotrienol isomers was lower in M-mayo (ranging from 11.86 to 30.76%) than in O-mayo (ranging from 22.23 to 34.15%). β-tocotrienol was the most unstable isomer in both types of mayonnaises during storage. In sensory evaluation, M-mayo obtained the highest rating for colour (7.60), while other sensory attributes (aroma, taste, creaminess, sourness, and overall acceptability) obtained similar ratings (ranging from 6.45 to 7.29) with other samples. Overall, the results showed that mayonnaise fortified with TRF microcapsule was able to reduce oxidation, and enhance their nutritional properties without affecting the sensory properties.

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Introduction

Mayonnaise is one of the most widely consumed dressings. It is a semi-solid dressing with creamy white colour and a slightly sour taste. Traditional mayonnaise is an oil-in-water emulsion that consists of a high portion of oil (65 to 85%). It is produced at an acidic condition with a pH ranging from 3.7 to 4.2 (Akhtar and Masoodi, 2022). Mayonnaise is mainly formulated by mixing vegetable oil, water, egg yolk, mustard, vinegar or lemon juice, salt, and seasoning ingredients (Abdolmaleki *et al*., 2019). There are three components in mayonnaise, which are dispersed phase, continuous phase, and interface. The dispersed phase of the mayonnaise consists of vegetable oil, the continuous phase consists of vinegar and water, and the interface is made up of egg yolk which acts as an emulsifier (Li *et al*., 2014).

Nowadays, traditional mayonnaise no longer fits the demand of consumers due to increasing healthy eating trends. For this reason, several studies have been conducted by some researchers to enrich mayonnaise with different natural antioxidants such as resveratrol, tocopherol, rosemary essential oil, and *Ferulago angulata* extract (Abdolmaleki *et al*., 2019; Rabbani *et al*., 2021). The addition of natural antioxidants to the mayonnaise can potentially enhance the oxidative stability of oil (Gorji *et al*., 2016). Furthermore, the fortification of a natural antioxidant into the mayonnaise can provide health-promoting benefits to achieve two purposes, which

*Corresponding author.
Email: tancp@upm.edu.my

are healthy and natural. This enables mayonnaise producers to target a wider group of consumers (Hermund and Yes, 2015).

In recent years, tocotrienols have gained a lot of attention as it was proven to have excellent antioxidative properties, apart from tocopherol. Both vitamin E components were well reported to play an important role to prevent numerous diseases like atherosclerosis, neurodegeneration, cancers, and aging that are caused by reactive oxygen and nitrogen species that lead to oxidation (Park *et al*., 2010; Sen *et al*., 2010). The structure of tocotrienol consist of an isoprenoid side chain (Sultana *et al*., 2023). Moreover, tocotrienols effectively neutralise peroxyl radicals to inhibit the propagation phase of lipid oxidation. Therefore, it delays rancidity of oil, and preserve the quality of oil during storage (Sultana *et al*., 2023). According to the recommended dietary allowance (RDA), the daily intake of vitamin E for adolescent, adult men, and non-lactating women should be 15 mg (22.5 IU). In the United States, above 90% of individuals do not meet the vitamin E requirement as stated by RDA (Saini and Keum, 2016). Therefore, it is encouraged to fortify TRF into the food products such as mayonnaise to increase the intake of vitamin E.

The major problem encountered when fortifying the pure form of polyunsaturated tocotrienols into food products is due to their instability against lipid oxidation. Tocotrienols are highly susceptible to oxidation when expose to various environmental stress like heat, light, oxygen, moisture, and pH. The low pH of mayonnaise promotes the hydrolytic degradation of ester bonds in tocotrienol compounds, causing the less active and undesirable by-products to form (Ko *et al*., 2010). As a result, the antioxidant potential of tocotrienols is reduced (Colombo, 2010). In addition, the interaction between bioactive compounds with other ingredients in the mayonnaise, like water and lipids, could lead to the degradation of these bioactive compounds (Dima *et al.*, 2020). Besides, the high-oil-content mayonnaise undergoes oxidation rapidly, and the degradation of tocotrienol will be accelerated as it primarily acts as an antioxidant (Colombo, 2010). Moreover, the hydrophobic tocotrienol has low water solubility and intestinal permeability when ingested orally, this has resulted in difficulty to incorporate a pure form of tocotrienol into food products (Alayoubi *et al.*, 2013). Another challenge is that the incorporation of tocotrienol can affect the sensory properties of food products adversely as the highly perishable tocotrienol has an unfavourable aroma and unpleasant taste (Maqsoudlou *et al*., 2020).

To resolve these issues, microencapsulation has become the solution to enhance the stability of tocotrienols from degradation during storage or environmental stress conditions. Fortification of encapsulated tocotrienol into yoghurt displayed a lower degradation (50.8%) as compared to non-encapsulated tocotrienol (87.5%) (Tan *et al*., 2018). Additionally, studies on microencapsulation of algae oil (Mu *et al*., 2022), sun flower oil (Le Priol *et al*., 2019), and green coffee oil (Mu *et al*., 2024) also exhibited improved oxidative stability of bioactive compounds during storage. In the present work, a TPPI was created through pH-shifting and thermal treatments to form a complex with FG, resulting in a TPPI:FG (3:1) complex. This complex acted as an emulsifier, stabilising TRF in the form of Pickering nanoemulsion. This approach would be suitable for producing natural and vegan food products as it relies on a fully plant-based emulsifier, eliminating the need for synthetic or animal-based emulsifiers.

Additionally, in the present work, the TRF-based microcapsule was produced by the maltodextrin-starch sodium octenyl succinate, M:OSS (8:2). Maltodextrin is suitable to be used as wall material due to its low viscosity, high water solubility, and high stability against thermal and acidic conditions, whereas OSS has good emulsifying and thickening properties (Liu *et al.*, 2018; Saavedra-Leos *et al.*, 2022). Therefore, the microcapsule produced by M:OSS (8:2) could form a strong, compact, and thick layer around the TRF to protect it against lipid oxidation.

In this context, the mayonnaise was fortified with TRF in the form of microcapsule and bulk oil, respectively. The physico-chemical properties and oxidative stability of the TRF-fortified mayonnaise were determined over four weeks of storage at 4°C. The sensory properties, such as colour, aroma, taste, creaminess, sourness, and overall acceptability of the mayonnaise samples were also evaluated in the present work by performing sensory evaluations using a 9-point hedonic scale.

Materials and methods

Materials

Raw materials needed to prepare the mayonnaise, such as soybean oil, egg yolk, vinegar, cheese powder, mustards, and salt (Table 1), were purchased from a local supermarket in Ampang, Selangor, Malaysia. The palm TRF was kindly provided by ExcelVite Sdn. Bhd. (Chermo, Malaysia), which consisted of 50% oil suspension with major compounds of d-γ (17.5%), d-δ (4.0%), d-β (1.9%), d-α-tocotrienol (9.5%), and d-α-tocopherol (9.5%). PPI and FG were purchased from Emsland Group Sdn. Bhd. (Wietzendorf, Germany) and Qingdao Dehui Halobios Science and Technology Co., Ltd. (Qingdao, China), respectively. The wall materials of maltodextrin were purchased from V.I.S. Foodtech Ingredient Supplies Sdn. Bhd. (Kepong, Malaysia), and OSS were purchased from Ingredion Incorporated (Westchester, USA). The high-performance liquid chromatography (HPLC) grade standard of (d-α-, β-, γ-, and δ-) tocopherol and (d-α-, β-, γ-, and δ-) tocotrienol mixtures were purchased from ChromaDex (Los Angeles, USA). HPLC grade *n*-hexane and 1,4-dioxane were purchased from Fisher Scientific (Pittsburgh, USA).

Table 1. Formulations of mayonnaises.

Ingredient	Percentage (%)		
	C-mayo	**O-mayo**	**M-mayo**
Soybean oil	75.0	74.4	72.0
Egg yolk	8.0	8.0	8.0
Vinegar	6.0	6.0	6.0
Water	5.0	5.0	5.0
Cheese powder	4.5	4.5	4.5
Mustard	1.0	1.0	1.0
Salt	0.5	0.5	0.5
TRF-based microcapsule	-	-	3.0
TRF bulk oil	-	0.60	-

TRF: tocotrienol-rich fraction; C-mayo: control mayonnaise; O-mayo: mayonnaise containing TRF bulk oil; and M-mayo: mayonnaise containing TRF-based microcapsule.

Preparation of TRF-based microcapsule

The TPPI was prepared by pH-shifting and thermal treatment following the method modified from Yi *et al*. (2021). The PPI solution was dissolved overnight at pH 12.0 ± 0.2. Then, the PPI solution was placed in the water bath at 88°C for 30 min with continuous stirring. Subsequently, the solution was immediately brought down to 25°C under running tap water, and the pH was adjusted to pH 6.0 ± 0.2 with continuous stirring at 750 rpm for 10 min. Next, the clear TPPI solution was obtained after centrifuge using a centrifuge machine X1 (Thermo Scientific, Waltham, USA) at 8,610 rpm for 15 min. The FG was dissolved overnight with continuous stirring at 500 rpm to ensure complete hydration. Lastly, a total concentration of 2% (w/w) TPPI:FG (3:1) complex that made up of TPPI and FG solutions in a weight ratio of 3:1 were stirred at 650 rpm for 30 min. Then, the TPPI:FG (3:1) complex was used to prepare the microcapsule in the subsequent steps.

The TRF-based microcapsule was made up of lipid to aqueous phase ratio of 1:9, and core-to-wall ratio of 1:4. The microcapsule consisted of 10% (w/w) palm TRF, 2% (w/w) of TPPI-FG (3:1) complex, 38% (w/w) wall material, 0.01% (w/w) sodium azide, and the remaining 50% were distilled water. The wall material was made up by maltodextrin and OSS in a mixing ratio of 8:2 (w/w), and denoted as M:OSS (8:2). Firstly, the aqueous and lipid phases were heated to 40°C. A high-pressure homogeniser (Silverson L4R, Silverson Machines Ltd., Chesham, England) was employed to homogenise the lipid and aqueous phases at 7,500 rpm for 5 min to form coarse emulsion. Subsequently, the coarse emulsion was further subjected to high-pressure homogenisation (Panda 2K, Niro Soavi, Deutschland, Lubeck, Germany) at 80 mPa for five cycles to produce fine nanoemulsions. Then, the nanoemulsion was converted into powder by using an optimised spray drying condition that was done during preliminary study.

A pilot-scale spray dryer (GEA Niro A/S, Mobile Minor 2000, Denmark) was utilised to spray dry the homogenised nanoemulsions, with inlet and outlet temperatures of 170 and 90°C, respectively, to produce microcapsules. The pump rate ranged from 10 to 12 mL/min, and the aspiration rate remained at 100%. The resulting powders were sealed in an air-tight amber glass bottle, and stored at room temperature for subsequent analysis.

Preparation of TRF-fortified mayonnaise

The mayonnaise samples were prepared following the method modified from Ribes *et al.* (2019). Firstly, a small amount of water was added to dilute the viscous mustard paste. The egg yolk was then added into the mixing bowl, and blended at medium speed for 30 s. The mustard paste was introduced into the mixing bowl, and blended at medium speed for 2 min with a wire whip. During the next 15 min, soybean oil was slowly added at high speed, with approximately 10% of the soybean oil and TRF bulk oil (for O-mayo only) added during the first 5 min. This involved gradually adding a small amount of soybean oil, followed by a 30-s interval between each addition. In the subsequent 5 min, approximately 50% of the soybean oil was added, and during the final 5 min, the remaining soybean oil was incorporated into the mixing bowl. Subsequently, the dissolved salt, cheese powder, TRF-based microcapsule (for M-mayo only), vinegar, and the remaining water were stirred until fully dissolved. The mixture was blended at medium speed for 2 min, followed by an additional 1 min at low speed. The resulting mayonnaise samples were stored at 4°C for further analysis.

Storage stability

The mayonnaise samples (C-mayo, M-mayo, and O-mayo) were kept in an air-tight glass jar, stored in a chiller at 4°C, and samples were taken for analysis at weeks 0, 1, 2, 3, and 4 of storage. The physico-chemical properties of the mayonnaise samples were evaluated based on colour, pH, viscosity, and texture, whereas the oxidative stability was measured by peroxide value (PV) and degradation of tocopherol and tocotrienols.

Colour

The colour of the mayonnaise samples was measured by direct reading using a Chroma meter CR-410 (Konica Minolta, Japan). According to the CIE (International Commission on Illumination), the value of L* represents brightness, ranging from white (100) to black (0), a* represents green (-a*) and red (+a*), and b* represents blue (-b*) and yellow (+b*).

pH

The pH of the mayonnaise samples was measured using a pH meter (Hanna Instrument PH 211, Microprocessor pH 151 Meter, Italy) at 25 ± 2°C.

Viscosity

The viscosity of the mayonnaise samples was determined using a rheometer (RheolabQC, Anton Paar GmbH, Graz, Austria) equipped with a concentric cylinder measuring system. The mayonnaise was filled until the filling level mark inside the cylindrical cup. The viscosity was measured at 4 ± 2°C using a shear rate of 100/s.

Texture

The texture of the mayonnaise samples was measured using a TA-XT2i texture analyser (Stable Micro System, Massachusetts, USA) equipped with SMSP/0.5 probe. The texture profile analyser was operated using a 2 mm/s test speed, and 10 mm test distance. The mayonnaise samples were characterised based on firmness, consistency, and cohesiveness.

Peroxide value

The extraction of oil from the mayonnaise samples for PV determination was performed following the method adopted from Chang *et al*. (2018). The mayonnaise (0.5 g) was suspended with 2.5 mL of deionised water, and stirred at 300 rpm for 30 min to ensure the dissolution of the mayonnaise. Then, the suspension (300 µL) was added with 1.5 mL of an iso-octane/isopropanol (2:1) mixture, and vortexed for 10 s, 3 times to extract the oil. The resultant solution was centrifuged at 1,000 *g* for 4 min. The extraction was repeated three times. The PV of extracted oil was measured spectrophotometrically according to IDF standard 74A:1991. The resultant solution (400 µL) was added with 9.6 mL of chloroform/methanol (7:3) mixture. To form colour, iron (II) chloride solution (50 µL) was added and vortexed for 5 s. Subsequently, ammonium thiocyanate solution (50 µL) was added and vortexed for another 5 s. The resultant solution was allowed to react for 5 min in dark conditions. Then, the absorbance was measured using a UV-VIS spectrophotometer (Agilent Technologies, CARY 60 UV-VIS, California, USA) at 500 nm in triplicates in subdued light within 10 min. PV was calculated using iron (III) calibration curve as shown in Eq. 1:

$$\text{PV (mEq /kg oil)} = \frac{(Abs_{sample} - Abs_{blank})}{(\text{S} \times 55.84 \times 2 \times \text{W})} \quad \text{(Eq. 1)}$$

where, Abs_{sample} = absorbance of the oil sample, Abs_{blank} = absorbance of the blank, S = slope of the iron (III) standard curve, 55.84 = atomic weight of Fe (III), 2 = unit conversion factor, and W = sample weight.

Tocopherol and tocotrienol contents analysis

The TRF extraction and analysis method was adapted from Tan *et al*. (2000) with slight modifications. Briefly, 2 g of M-mayo and O-mayo were vortex-mixed with 5 mL of methanol for 2 min. The mixture was held at room temperature for 2 min.

Then, the mixture was added with 10 mL of *n*-hexane, and vortexed for 1 min. Next, 5 mL of deionised water was added to the mixture, and vortexed for 1 min. The resultant mixture was centrifuged at 10,000 rpm for 5 min. The supernatant layer was collected in a scintillation vial, and purged with nitrogen gas. About 24 mg of TRF extract was reconstituted with 1 mL of *n*-hexane, and vortex-mixed for 1 min. The resultant solution was filtered using a 0.45 µm polytetrafluoroethylene syringe filter. The filtrate was collected in an autosampler HPLC vial for analysis.

Tocotrienol and tocopherol contents analysis was slightly modified from Tan *et al*. (2000). The peaks of tocotrienol and tocopherol were evaluated using the HPLC system (Shimadzu) equipped with a fluorescence detector (Shimadzu, Prominence LC-20AD) and a C18 column (250 × 4.6 mm, 5 µm; Phenomenex, Torrance, CA, USA). The separation was performed using an isocratic mobile phase made up of *n*-hexane:dioxane:isopropanol (97.5%:2%:0.5 v/v/v) at a flow rate of 1 mL/min, and analysis time of 30 min. The injection volume was 20 µL, and the temperature of the column was adjusted to 30°C. The fluorescence detector was set at the excitation wavelength of 295 nm.

The α-tocopherol and α-, β-, γ-, and δ-tocotrienols were evaluated from the mayonnaise samples. It was quantified by referring to the external calibration curves ($R^2 \geq 0.99$) established for the mixture isomers using the reference standard mixture. The standard solutions were prepared at concentrations of 0.3 to 50 ppm by serial dilution of the standard mixture with *n*-hexane. The standard solutions were injected in triplicates to determine the content of tocopherol and tocotrienols using the linear calibration curves. The degradation of tocopherol and tocotrienols in the mayonnaise samples over four weeks of storage was calculated using Eq. 2:

$$\text{Degradation (\%)} = \frac{(T_0 - T_n)}{T_0} \times 100 \qquad \text{(Eq. 2)}$$

where, T_0 = tocotrienol content in the mayonnaise samples in week 0, and T_n = tocotrienol content in the mayonnaise samples in the subsequent week.

Sensory evaluation

A sensory evaluation (approval no.: JKEUPM-2023-814) of the TRF-fortified mayonnaise samples was conducted with the participation of 60 panellists. These panellists were selected following the general guidelines of UNE-ISO 8586:2012. Various preparatory sessions were held to familiarise the panellists with the sensory analysis process, enabling them to recognise and score the quality attributes associated with each sample. The assessments were carried out using a structured 9-point hedonic scale (ranging from 1: "dislike extremely", to 9: "like extremely"), as outlined in UNE-ISO 4121:2003. This scale was employed to evaluate the colour, aroma, taste, creaminess, sourness, and overall acceptability of the mayonnaise.

The panellists were presented with three distinct mayonnaise samples for assessment: (i) C-mayo (control); (ii) O-mayo (mayonnaise containing TRF bulk oil); and (iii) M-mayo (mayonnaise containing TRF-based microcapsule). The sensory analysis took place within 1 h of sample preparation, with the samples stored at 4°C in sealed glass jars during this time. Each sample was served to the panellists in transparent plastic glass, labelled with three arbitrary digits. To prevent aftertaste, the panellists were instructed to consume an unsalted cracker, and drink water in between samples, following the protocol outlined by Ribes *et al*. (2017).

Statistical analysis

All the analyses were done in triplicates on duplicate samples. The results were analysed using the Minitab statistical software version 17.0 (Minitab Inc., PA, USA). The One-way ANOVA (*post hoc* Tukey's test) was adopted to determine the significant differences among mean values ($p < 0.05$).

Results and discussion

Colour

It is important to measure the colour of the TRF-fortified mayonnaises as it is one of the sensory attributes that can influence consumer preference. Based on Table 2, all the fresh mayonnaise samples presented light colour with a higher tendency to red (positive a* value) and yellow (positive b* value). The yellowness of the mayonnaise samples was mainly contributed by the addition of cheese powder and TRF. The fresh M-mayo had a significantly ($p <$ 0.05) lower L* value, and higher a* and b* values than fresh O-mayo and C-mayo. As depicted in Figure 1, M-mayo had the darkest yellow colour due to the significant influence from the wall material of TRF-based microcapsule that changed the light-

Table 2. Effect of storage on pH, colour, texture, and viscosity of different mayonnaise samples.

Parameter	Sample	Week 0	Week 1	Week 2	Week 3	Week 4
pH	C-mayo	4.18 ± 0.08^{bA}	4.25 ± 0.02^{abA}	4.24 ± 0.01^{abA}	4.25 ± 0.02^{abA}	4.28 ± 0.01^{aA}
	O-mayo	4.18 ± 0.02^{cA}	4.26 ± 0.01^{bA}	4.25 ± 0.01^{bA}	4.25 ± 0.01^{abA}	4.25 ± 0.01^{aA}
	M-mayo	4.17 ± 0.04^{bA}	4.25 ± 0.01^{aA}	4.25 ± 0.01^{aA}	4.25 ± 0.02^{aA}	4.28 ± 0.01^{aA}
Colour L*	C-mayo	77.61 ± 0.29^{cA}	77.80 ± 0.12^{cA}	78.29 ± 0.20^{bcA}	79.34 ± 0.33^{bA}	81.90 ± 1.04^{aA}
	O-mayo	75.23 ± 0.49^{dB}	76.53 ± 0.36^{dB}	75.65 ± 0.11^{cB}	76.21 ± 0.21^{bC}	77.22 ± 0.17^{aC}
	M-mayo	74.81 ± 0.18^{cB}	74.34 ± 0.18^{cC}	75.33 ± 0.34^{cB}	75.66 ± 0.28^{abB}	75.70 ± 0.17^{aB}
Colour a*	C-mayo	8.61 ± 0.12^{cC}	9.28 ± 0.37^{bB}	9.60 ± 0.17^{bB}	10.28 ± 0.09^{aA}	10.58 ± 0.07^{aA}
	O-mayo	9.31 ± 0.04^{dB}	9.64 ± 0.25^{cB}	9.95 ± 0.67^{bA}	9.93 ± 0.03^{bA}	11.84 ± 0.06^{aA}
	M-mayo	10.80 ± 0.08^{bA}	10.54 ± 0.37^{abA}	10.05 ± 0.07^{abA}	11.00 ± 1.19^{abA}	11.61 ± 0.13^{aB}
Colour b*	C-mayo	37.76 ± 0.53^{bC}	39.41 ± 0.53^{aB}	39.44 ± 0.47^{aB}	39.85 ± 0.73^{aB}	40.30 ± 0.67^{aC}
	O-mayo	43.27 ± 0.60^{cB}	47.59 ± 0.50^{bA}	47.58 ± 0.25^{bA}	48.15 ± 2.12^{bA}	52.46 ± 0.15^{aA}
	M-mayo	46.12 ± 0.54^{eA}	47.35 ± 0.13^{dA}	48.31 ± 0.47^{cA}	49.44 ± 0.23^{bA}	50.32 ± 0.35^{aB}
Firmness (g)	C-mayo	16.94 ± 0.28^{dB}	27.50 ± 2.38^{cB}	28.73 ± 0.20^{bcB}	31.08 ± 0.64^{abB}	33.49 ± 1.08^{aB}
	O-mayo	18.38 ± 0.31^{dB}	27.07 ± 0.91^{cB}	28.87 ± 1.45^{bcB}	29.45 ± 0.57^{abB}	31.27 ± 1.02^{aB}
	M-mayo	31.75 ± 2.21^{bA}	33.30 ± 2.18^{bA}	34.74 ± 1.03^{bA}	43.45 ± 1.3^{abA}	45.98 ± 2.25^{aA}
Consistency (g.s)	C-mayo	29.09 ± 0.99^{cC}	96.21 ± 1.73^{bC}	98.52 ± 2.26^{bB}	103.33 ± 1.98^{aB}	103.72 ± 1.71^{aB}
	O-mayo	32.75 ± 1.38^{dB}	78.06 ± 1.20^{cB}	97.47 ± 1.54^{bB}	103.14 ± 0.50^{aB}	105.61 ± 3.79^{aB}
	M-mayo	46.51 ± 1.61^{dA}	126.58 ± 3.05^{cA}	142.80 ± 1.98^{bA}	146.26 ± 4.12^{abA}	151.89 ± 1.67^{aA}
Cohesiveness (g)	C-mayo	-9.49 ± 0.15^{cA}	-15.64 ± 0.54^{cA}	-15.80 ± 0.71^{bA}	-17.54 ± 0.36^{bA}	-17.67 ± 0.71^{aA}
	O-mayo	-10.86 ± 0.59^{dB}	-14.47 ± 0.35^{cB}	-16.58 ± 0.35^{cA}	-17.13 ± 0.37^{bA}	-18.19 ± 0.42^{aA}
	M-mayo	-15.69 ± 0.60^{dC}	-22.33 ± 0.39^{dC}	-24.18 ± 0.40^{cB}	-25.61 ± 0.26^{bB}	-25.61 ± 0.22^{aB}
Viscosity (mPa.s)	C-mayo	1856.30 ± 23.80^{cB}	1861.40 ± 21.40^{cB}	1875.36 ± 15.99^{bcB}	1921.4 ± 45.40^{bB}	2021.13 ± 7.89^{aB}
	O-mayo	1439.79 ± 13.28^{cC}	1779.90 ± 91.20^{bB}	1812.80 ± 2.31^{abC}	1914.70 ± 61.30^{aB}	1920.20 ± 35.70^{aC}
	M-mayo	2510.30 ± 55.70^{dA}	2799.30 ± 58.90^{cA}	2807.55 ± 10.10^{cA}	2899.60 ± 22.90^{bA}	3044.75 ± 6.87^{aA}

Values are mean ± standard deviation (n = 6). Means with different uppercase superscripts within similar column are significantly different (p < 0.05). Means with different lowercase superscripts within similar row are significantly different (p < 0.05). C-mayo: control mayonnaise; O-mayo: mayonnaise containing TRF bulk oil; M-mayo: mayonnaise containing TRF-based microcapsule; L*: Lightness; a*: (+) red/(−) green; and b*: (+) yellow/(−) blue.

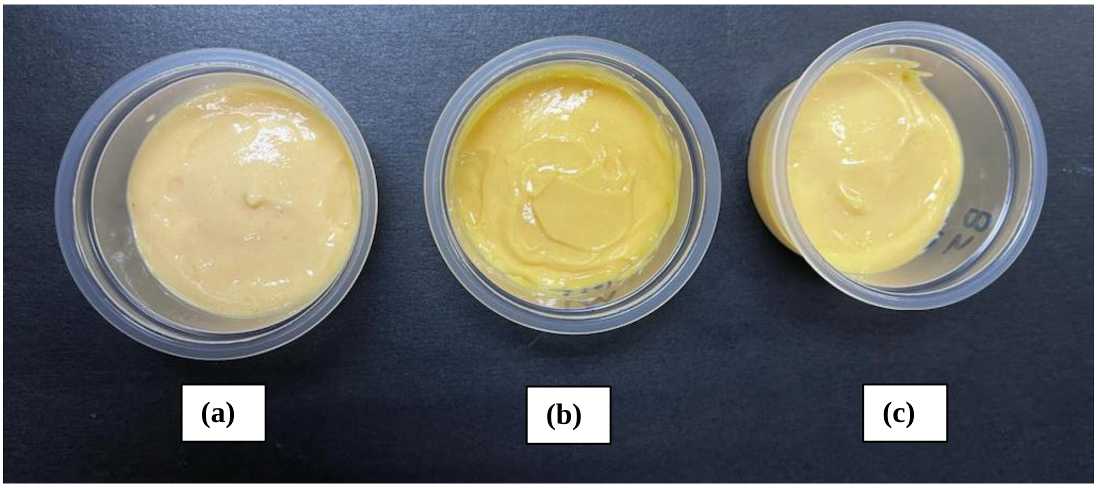

Figure 1. Fresh mayonnaise samples prepared from different formulations: **(a)** control mayonnaise (C-mayo); **(b)** mayonnaise containing TRF-based microcapsule (M-mayo); and **(c)** mayonnaise containing TRF bulk oil (O-mayo).

scattering particles in the mayonnaise. Throughout the storage period, the L*, a*, and b* values of all the mayonnaise samples significantly increased ($p < 0.05$). The percentage of change after four weeks of storage with respect to week 0 for L*, a*, and b* values of M-mayo (1.19, 7.50, and 9.11%) were lower than O-mayo (2.65, 27.18, and 21.24%), which indicated that the encapsulated TRF was more stable during storage. The TRF was successfully enclosed by TPPI-FG (3:1) complex, and retained steadily in M:OSS (8:2) wall materials to minimise the deterioration effect at acidic conditions. Based on previous findings, the TRF-based microcapsule was found to obtain high encapsulation efficiency (94.63%), and low TRF release (3.37 to 3.59%) at pH 3 to 5. Therefore, it minimised the deterioration of TRF in mayonnaise, and resulted in minimum colour change. As compared to O-mayo, the TRF was unprotected and more susceptible to lipid oxidation which resulted in higher colour change. Therefore, the results showed that the encapsulated TRF would be better to maintain the colour of the mayonnaise under prolonged storage.

pH

The pH levels of the mayonnaise samples after storage are tabulated in Table 2. The pH levels were similar regardless of the types of mayonnaise. This showed that the addition of TRF had no significant effect on the pH of the mayonnaise samples. However, the pH for all mayonnaise samples increased slightly during storage. This might have been due to the degradation of acetic acid from vinegar over time (Sørensen *et al.*, 2010). The final pH values ranged between 4.25 to 4.28, which fell within the microbiological safety pH range (pH 3.6 to 4.2) for mayonnaise (Hill *et al.*, 2020).

Viscosity

The viscosity of the mayonnaise samples is tabulated in Table 2. Based on the findings, M-mayo obtained the highest viscosity, followed by C-mayo and O-mayo. This could have been due to the addition of TRF-based microcapsules that were produced from TPPI-FG (3:1) complex and M:OSS (8:2) wall materials. FG has thickening properties while both maltodextrin and OSS have hydrophobic properties. These ingredients caused the viscosity of M-mayo to increase as they thickened the mayonnaise network. The thickening effect is desirable as it helps to reduce the oil release as the movement of the droplets are restricted under limited thermodynamic entropy (Akhtar and Masoodi, 2022). In contrast, the TRF in O-mayo was fortified directly from the bulk oil, therefore, the viscosity was lower. After four weeks of storage, there was a lower increment of viscosity for M-mayo (21.29%) as compared to O-mayo (33.27%). This was attributed to the thickening effect following the addition of the microcapsule which absorbed water and swelled. The thickening properties created a desired texture of mayonnaise, and maintained the consistency. One review article highlighted on the better viscosity retention with the addition of OSS in food, which enhanced the stability of food emulsion during storage (Massoud *et al.*, 2021). The viscosity of the mayonnaise can be correlated to the diameter of the oil droplets (Katsaros *et al.*, 2020). The lower the increment of the droplet's diameter, the lower the increment of the final viscosity. Therefore, it can be assumed that the oil droplet of M-mayo was more stable due to the thickening effect following the addition of the microcapsule. The thickening effect slowed down the movement of continuous phase, which reduced the movement of oil droplets in the mayonnaise. This then reduced the collision between oil droplets, which minimised the occurrence of coalescence, and prevented phase separation (McClements, 2015). Besides, the viscosity of the mayonnaise could also be affected by the emulsifier interaction. In M-mayo, the emulsifier from the microcapsule could enhance the interfacial tension, resulting in a more stable emulsion with minimal changes in viscosity. In contrast, fortification of TRF bulk oil might have disrupted the emulsifier interaction at the oil-water interface, causing greater impact on viscosity. It is, therefore, important to study the viscosity of mayonnaise as it can affect the mayonnaise mouthfeel, texture, and spreadability.

Texture

The textural properties (firmness, consistency, and cohesiveness) of the mayonnaise samples were evaluated as they were affected by the incorporation of TRF and storage period. Generally, O-mayo obtained more similar textural properties to C-mayo. Firmness determines the textural property of the food system, which measures the force required to reach the maximum depth, whereas cohesiveness refers to the degree of deformation of the sample before it fractures; it measures the force required to pull the probe out from the sample (Gutiérrez *et al*., 2016). Based on Table 2, M-mayo obtained the highest firmness, consistency, and cohesiveness compared to O-mayo and C-mayo. As explained earlier, the ingredients of TRF-based microcapsule caused a thickening effect on the mayonnaise; as a result, the texture of M-mayo became more viscous and firm. In addition, a higher firmness in M-mayo could have been due to the formation of a complex between TPPI and FG that increased the stiffness of the gel matrix. Hence, M-mayo had higher mechanical stability against rupture. Moreover, mayonnaises are oil-in-water emulsions that mostly consist of oil. The incorporation of microcapsules increased the solid content of the mayonnaises; making them more consistent and cohesive. As storage time increased, all the textural values of all mayonnaise samples increased ($p < 0.05$). The increase in textural values might have been due to the loss of water from the mayonnaise matrix during storage. This could have been due to the acidic condition of mayonnaise that altered the charge of emulsifier (egg yolk), which contributed to electrostatic repulsion, causing coalescence of oil droplets and water loss (Anton, 2013). Besides, M-mayo showed the lowest changes in firmness (44.8%) as compared to O-mayo (70.1%) and C-mayo (97.7%) over the storage period. The thickening agents from the microcapsule enhanced the water-holding capacity of the mayonnaise, hence, reducing the syneresis rate of mayonnaise (Dickinson, 2009).

Peroxide value

The formation of primary oxidation products was determined by measuring the PV of the TRF-fortified mayonnaise samples (O-mayo and M-mayo) over four weeks storage period (Table 3). As seen from the results, the PV of M-mayo was lower ($p < 0.05$) than O-mayo from week 0 to week 4. The result indicated that the encapsulated TRF was more oxidatively stable. This could have been due to the presence of wall material which acted as a protective layer around the TRF active compound. The results agreed with Tan *et al*. (2018), such that microencapsulated tocotrienol was more stable towards lipid oxidation as compared to unencapsulated tocotrienol when incorporated into yoghurt. However, the PV of M-mayo increased gradually over storage. This showed that the TRF in M-mayo still experienced oxidation even though it was encapsulated within the wall materials. This was because the properties of the wall material have experienced alteration after being incorporated into the mayonnaise under prolonged storage. The oil would diffuse out from the core to the surface of the microcapsule by molecular diffusion (Ferreira *et al*., 2016). As a result, the surface oil was exposed to pro-oxidants which rendered it prone to oxidation (Kha *et al*., 2015). Hence, it caused the PV to increase

Table 3. Effect of storage on peroxide value and degradation of tocopherols and tocotrienols in different mayonnaise samples.

Parameter	Sample	Week 0	Week 1	Week 2	Week 3	Week 4
Peroxide value (mq/kg)	O-mayo	0.70 ± 0.01^{eA}	3.97 ± 0.01^{dA}	4.33 ± 0.01^{cA}	7.27 ± 0.01^{bA}	8.62 ± 0.00^{aA}
	M-mayo	0.36 ± 0.01^{dB}	0.42 ± 0.00^{dB}	1.34 ± 0.09^{cB}	1.84 ± 0.02^{bB}	2.66 ± 0.00^{aB}
α-tocopherol (%)	O-mayo	0.00 ± 0.00^{dA}	20.52 ± 0.00^{cA}	23.30 ± 1.92^{bcA}	26.28 ± 0.63^{abA}	27.98 ± 0.30^{aA}
	M-mayo	0.00 ± 0.00^{eA}	5.17 ± 0.00^{dB}	9.33 ± 0.00^{cB}	13.89 ± 0.37^{bB}	18.74 ± 0.05^{aB}
α-tocotrienol (%)	O-mayo	0.00 ± 0.00^{cA}	22.60 ± 0.00^{bA}	24.45 ± 2.31^{abA}	27.35 ± 0.90^{aA}	28.77 ± 0.47^{aA}
	M-mayo	0.00 ± 0.00^{dA}	7.99 ± 0.00^{cB}	8.85 ± 0.33^{cB}	14.62 ± 2.07^{bB}	19.39 ± 1.09^{aB}
β-tocotrienol (%)	O-mayo	0.00 ± 0.00^{cA}	25.10 ± 0.00^{bA}	28.78 ± 0.00^{abA}	29.89 ± 1.49^{abA}	34.15 ± 3.62^{aA}
	M-mayo	0.00 ± 0.00^{dA}	17.99 ± 2.35^{cA}	24.52 ± 1.83^{bA}	27.33 ± 0.34^{abA}	30.76 ± 0.64^{aA}
γ-tocotrienol (%)	O-mayo	0.00 ± 0.00^{cA}	14.00 ± 1.72^{bA}	17.38 ± 2.05^{abA}	20.81 ± 0.57^{aA}	22.23 ± 0.21^{aA}
	M-mayo	0.00 ± 0.00^{dA}	3.92 ± 0.00^{cB}	4.37 ± 0.05^{cB}	7.36 ± 0.26^{bB}	11.86 ± 0.48^{aB}
δ-tocotrienol (%)	O-mayo	0.00 ± 0.00^{eA}	17.65 ± 0.14^{dA}	20.40 ± 0.00^{cA}	21.76 ± 0.00^{bA}	29.23 ± 0.07^{aA}
	M-mayo	0.00 ± 0.00^{dA}	6.35 ± 0.00^{cB}	12.50 ± 0.61^{bB}	13.29 ± 0.46^{bB}	19.38 ± 1.13^{aB}

Values are mean ± standard deviation ($n = 6$). Means with different uppercase superscripts within similar column are significantly different ($p < 0.05$). Means with different lowercase superscripts within similar row are significantly different ($p < 0.05$). C-mayo: control mayonnaise; O-mayo: mayonnaise containing TRF bulk oil; M-mayo: mayonnaise containing TRF-based microcapsule.

gradually over time. In contrast, the TRF in O-mayo was highly susceptible to lipid oxidation as it was directly exposed to harsh environmental conditions. Thus, the increment of PV was higher. According to the Codex Alimentarius in 2001, oil with PV below 5 $mEqO_2/kg$ is categorised as good oil, while oil with PV above 10 $mEqO_2/kg$ is categorised as rancid oil. In the present work, the final PVs of both M-mayo and O-mayo were 2.66 ± 0.00 and 8.62 ± 0.00. The former can be considered as good quality oil, while the latter was close to rancid.

Degradation of tocopherol and tocotrienols

One tocopherol and four tocotrienol isomers were detected in the TRF-fortified mayonnaise samples (O-mayo and M-mayo) through HPLC analysis. The degradation of tocopherol and tocotrienols during four weeks of storage is tabulated in Table 3. As anticipated, the degradation of all the isomers was less distinct ($p < 0.05$) in M-mayo (11.86 ± 0.48 to 30.76 ± 0.64%) as compared to O-mayo (29.23 ± 0.07 to 34.15 ± 3.62%). Consistent with the finding of Tan *et al.* (2018), the degradation of tocotrienol isomers was lower when the encapsulated TRF was fortified into yoghurt as compared to bulk oil. This is because the encapsulated TRF was protected by the thick and compact wall materials made up of M:OSS (8:2), which limited the contact of pro-oxidants in the mayonnaise. The earlier results of the present work showed that the wall material had very high encapsulation efficiency (94.63 ± 2.56%), and was very resistant to acidic conditions (3.37 ± 0.28 to 3.59 ± 0.37% of TRF released at pH 3 to 5). In addition, a lower PV value was found in M-mayo, which further proved that the degradation of the isomers was lower as compared to O-mayo. Based on the results obtained, the degradation orders of tocopherol and tocotrienol isomers in both mayonnaise samples were as follows: β-tocotrienol > δ-tocotrienol > α-tocotrienol > α-tocopherol > γ-tocotrienol. Other studies also reported that β-tocotrienol was the most susceptible to degradation as compared to other isomers (Tan *et al.*, 2018; Surjit Singh *et al.*, 2022). This is attributed to its lower antioxidant activity and intermediate methylation structure (Yoshida *et al.*, 2003).

Sensory evaluation

A total number of 60 panellists were invited to perform the sensory evaluation on three different mayonnaise samples (C-mayo, O-mayo, and M-mayo) based on several sensory attributes (colour, aroma, taste, creaminess, sourness, and overall acceptability). As seen in Table 4, the average score for the colour of M-mayo (7.60 ± 1.34) was the highest, followed by O-mayo (7.52 ± 1.37) and C-mayo (6.98 ± 1.47). This indicated that most of the panellists preferred the mayonnaise with a darker yellow colour as it seemed to be more attractive and tastier. Other than that, the aroma, taste, creaminess, and sourness attributes had no significant difference ($p > 0.05$) between these three samples. This indicated that panellists had similar degrees of liking for these sensory attributes among the mayonnaise samples. The average scores of these attributes fell within the range of 6.45 to 7.29, which indicated that most of the panellists have chosen "like slightly" and "like moderately". This might have been due to the addition of cheese powder as a flavouring agent. The cheese powder created a pleasant cheesy and creamy taste to the mayonnaise which successfully masked the unpleasant aroma and taste of the TRF. The panellists could not differentiate the fortified and unfortified mayonnaises; thus, the average ratings were almost similar for all the samples. The overall acceptability of M-mayo (7.29 ± 1.31) was higher than C-mayo (7.27 ± 1.26) and O-mayo (7.27 ± 1.31), although there was no significant difference ($p > 0.05$). Of all mayonnaise samples, M-mayo obtained the highest sensory rating in terms of colour, sourness, and overall acceptability. Therefore, the results obtained were desirable as the TRF-fortified

Table 4. Sensory attributes of TRF-fortified mayonnaise samples based on hedonic ratings (n = 60)*.

Sample	Colour	Aroma	Taste	Creaminess	Sourness	Overall acceptability
C-mayo	6.98 ± 1.47^{B}	6.97 ± 1.43^{A}	7.07 ± 1.45^{A}	7.10 ± 1.30^{A}	6.77 ± 1.53^{A}	7.27 ± 1.26^{A}
O-mayo	7.52 ± 1.37^{AB}	7.02 ± 1.31^{A}	7.17 ± 1.46^{A}	7.28 ± 1.20^{A}	6.45 ± 2.14^{A}	7.27 ± 1.31^{A}
M-mayo	7.60 ± 1.34^{A}	6.98 ± 1.46^{A}	7.08 ± 1.36^{A}	6.93 ± 1.49^{A}	6.83 ± 1.62^{A}	7.29 ± 1.31^{A}

Values are expressed as mean ± standard deviation (n = 6). Means with different uppercase superscripts within similar column are significantly different ($p < 0.05$). C-mayo: control mayonnaise; O-mayo: mayonnaise containing TRF bulk oil; M-mayo: mayonnaise containing TRF-based microcapsule.

mayonnaises were highly accepted by the panellists, while the unpleasant aroma and taste of the TRF did not affect the panellists' preference.

Conclusion

The fortification of TRF-base microcapsules had significant effects on the colour, texture, and viscosity of the fresh mayonnaise. The overall findings suggested that the fortification of encapsulated TRF into the mayonnaise was more stable than bulk oil after storing at 4°C for four weeks. Based on the results obtained, M-mayo exhibited lower increments of lightness (1.19%), redness (7.50%), yellowness (9.11%), firmness (44.82%), consistency (63.22%), and viscosity (21.29%). Moreover, the M:OSS (8:2) microcapsules provided a distinct protection to TRF against oxidation as M-mayo yielded a significantly lower PV value (2.66 mq/kg) and degradation of tocopherol and tocotrienol isomers (ranging from 11.86 to 30.76%) at the end of the storage. Of all the tocopherol and tocotrienol isomers, β-tocotrienol was found to be the most unstable compound due to the highest percentage of degradation (30.76 ± 0.64 to 34.15 ± 3.62%) in both mayonnaise samples during storage. In sensory evaluation, M-mayo obtained the highest sensory rating in terms of colour, while other sensory attributes obtained similar degree of liking. The present work demonstrated the effect of storage and mayonnaise matrix on the stability of TRF encapsulated in M:OSS microcapsules. However, it was found that the degradation of encapsulated TRF could not be eliminated as oxidation still occurred in prolonged storage of mayonnaise. Therefore, further study can be conducted to enhance the stability of the active compounds by altering the preparation and/or processing parameters of the microcapsules.

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