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Omega-3-Enriched and Oxidative Stable Mayonnaise Formulated with Spray-Dried Microcapsules of Chia and Fish Oil Blends

Muhammad Abdul Rahim, Muhammad Imran,* Faima Atta Khan, Fahad Al-Asmari, Osama F. Mosa, Riyadh S. Almalki, and Eliasse Zongo*

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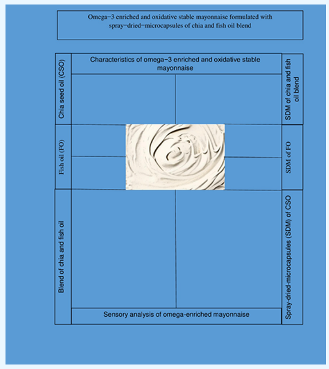
ABSTRACT: There is a growing demand for nutritious food products that contain specific ingredients, such as long-chain polyunsaturated fatty acids (LCPUFAs). In the case of LCPUFAs, protection against lipid peroxidation is difficult, and microencapsulation emerges as an alternative. The aim of this research work is to develop mayonnaise containing spray-dried microcapsules (SDM). Fortified mayonnaise was developed using various treatments such as (T_1) incorporating chia seed oil (CSO), (T_2) incorporating fish oil (FO), (T_3) incorporating blend of chia and fish oil, (T_4) incorporating the SDM of CSO, (T_5) incorporating the SDM of FO, and (T_6) incorporating the SDM of chia and fish oil blend as well as controls. Thereafter, during the 15-day storage period, the fatty acids (FAs) composition, free fatty acids (FFAs), peroxide value (PV), and sensory properties of fortified mayonnaise were examined every 5 days. The overall results showed that the oxidative stability of mayonnaise formulated with SDM has been improved, and it can be used as a fortifying agent in the processing of many food products. Treatments containing SDM of up to 4% did not differ from the control in sensory analysis. Sensory scores of SDM samples showed a slight decrease in off-flavor scores and were in an acceptable range. Therefore, SDM developed from CSO and FO blends can be recommended for supplementation in different food products for long-time storage.



1. INTRODUCTION

In recent decades, mayonnaise, also known as mayo, is a thick creamy sauce prepared by an oil-in-water emulsion (oil and whole egg) stabilized by emulsifying agents present in the egg yolk and egg white. It contains a higher concentration of fat content with a low pH, and the basic ingredients are oil, water, egg, and vinegar.[1] Nowadays, mayo is the most widely used in food products. Traditional mayo is an oil-in-water emulsion that has a higher nutritive value and reduces the amount of caloric content due to 74% oil contained in it.[2] Mostly, mayo contains oil, which is a good source of saturated fatty acids (SFAs). This oil content mostly contains SFAs. A higher consumption of SFAs is not good for human health and causes various chronic disorders. Accordingly, the use of healthy oils in mayonnaise includes oils rich in medium-chain fatty acids (FAs), polyunsaturated fatty acids (PUFAs), and long-chain polyunsaturated fatty acids (LCPUFAs). The components of LCPUFAs could have a positive impact on human health.[3]

The recommended daily intake of these LCPUFAs is very low in developing countries, and health experts recommend that daily intake of these LCPUFAs be improved through omega-enriched diets.[4] For this purpose, plant and marine sources have been recognized as excellent sources of LCPUFAs.[5] Chia seeds (CS) are gaining great attention due to their excellent source of PUFAs. It belongs to the mint family, and its plant name is *Salvia hispanica* L., and the chia is a kind of flowering plant. The oil content of CS varied between ~25 and 35%, which consists of up to 68% omega-3 (ω-3) FAs.[6] In addition, chia seed oil (CSO) contains large amounts of alpha-linolenic acid (ALA) and linoleic acid. CSO is a rich source of natural antioxidants like various types of tocopherols, bioactive or polyphenol compounds, and phytonutrients.[7] On the other hand, fish oil (FO) (*Labeo rohita*) is obtained from fish fillet, which has been recognized as a good source of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) contents. Many studies have shown that fish fillets contain up to 30% oil, including EPA (18%) and DHA (12%), respectively.[8] ω-3 FAs can decrease the risk factors of chronic diseases in humans.[9−13] Notably, blends of FO and CSO have been developed due to FO containing higher amounts of LCPUFAs (EPA and DHA), and unusually CSO is enriched in ALA contents.[14] It contains three types of ω-3 FAs (ALA,

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EPA, and DHA) and provides a compact nutritious oil with effective health benefits.[15]

These oil blends have potential health benefit applications in food processing, pharmaceutical, nutraceutical, and cosmetic industries for the production of value-added and food supplements or experimental products.[16] The oxidative stability of the blend is very low due to the environmental and processing factors.[17] Therefore, researchers and scientists are using various methods to improve the oxidative stability. For maintenance, different food industries most commonly use spray-drying processes due to their low cost and easy availability.[18,19] The consumer interest in oxidative stable ω-3-enriched products is almost dramatically increasing because of the increased health consciousness of modern people.[20,21] Therefore, the current study focuses on incorporating spray-dried microcapsules (SDM) with chia and fish oil blend into mayonnaise to produce an omega-enriched product with a high oxidative stability. The FAs profile, free fatty acids (FFAs) peroxide value (PV), and sensory evaluation of omega-enriched mayonnaise were examined after every fifth day during a 15-day storage period.

2. MATERIALS AND METHODS

2.1. Preparation of Raw Materials. The various ingredients used in the preparation of mayonnaise were obtained from registered stores and supermarkets in Punjab, Pakistan. Raw materials were cleaned to eliminate any other undesirable components. CSO and FO were extracted, as explained in the previous study by Rahim et al.[14] CSO was extracted from CS using the mini oil presser model 6YL-550 (Wuhan Acme Agro-Tech Co., Ltd., Zhengzhou, Henan, China), and FO was extracted from fish fillets using the solvent extraction method. In the solvent extraction method, methanol (100 mL) and chloroform (50 mL) were used as a solvent.

2.2. Emulsion Preparation for Spray Drying. The blends of CSO (50%) and FO (50%) were organized at room temperature (25 ± 2 °C) according to Rahim et al.[22] For spray drying, the emulsions were prepared, as reported by Costa et al.[23] Briefly, 1% soy lecithin was used for all oil blend formulations. Gum arabic and maltodextrin were added and gently stirred, and it was used in the emulsions as a wall material in the ratios of 1:1. The emulsions were homogenized using a homogenizer (FSH-2A, Changzhou, China) at 15,000 rpm for 7 min. After homogenizing, the emulsions were covered with aluminum foil and transferred to spray drying at room temperature.

2.3. Spray Drying of the CSO and FO Blend Emulsion. The CSO and FO blend emulsion was spray-dried using a lab-scale spray dryer (model: TPS-15, TOPTION, Shanghai, China) to prepare the SDM. In brief, the independent variables of spray drying such as the inlet air temperature (125 to 185 °C), wall material (5 to 25%), pump speed (3 to 7 mL/min), and needle speed (NS 3 to 11 s) were optimized, as described in the research work of Rahim et al.[8] The SDM were sealed in polythene zipper lock bags (local market, Faisalabad, Punjab, Pakistan) and kept at 25 ± 2 °C for a maximum of 2 weeks.

2.4. Development and Characterization of Fortified Mayonnaise. The fortified mayonnaise was prepared using the same method as described in the study of Rahmani-Manglano et al.,[24] with minor modifications. In this study, mayonnaise was developed following a fortified treatment plan with oils and their SDM: (T_1) incorporating CSO, (T_2) incorporating FO, (T_3) incorporating blend of chia and fish oil, (T_4) incorporating the SDM of CSO, (T_5) incorporating the SDM of FO, and (T_6) incorporating the SDM of chia and fish oil blend. In T_4 to T_6, 250 g of mayonnaise was developed using 4% SDM. In T_0, 250 g of mayonnaise was developed; 37.5% of the oil contained SFAs, 1% whole egg, 4% egg yolk, 1% filter water, 1.4% vinegar and lemon juice, 1% freshly ground black pepper, 0.3% salt, and 1% sugar. Initially, the egg yolk, 6 mL of salt solution (water and sodium chloride), freshly ground black pepper, and sugar were put in a blender and blended for 10 s. In the second stage, mixing started and vegetable oil was added slowly until the emulsion became creamy. Finally, vinegar and lemon juice were manually dissolved in the emulsion through a feed tube and mixed for 30 s at room temperature. For the treatment (T_1), 100 g of CSO was added with vegetable oil and blended for 10 to 20 s. In the treatment (T_2), 100 g of FO was added and blended for 10 to 15 s. Moreover, 100 g of chia and fish oil blend was added and blended. For the treatment (T_4), the SDM of CSO (50.5 g) was added and mixed. The SDM of FO (52.5 g) was added in the treatment (T_5) to the blender at this last step and mixed for 45 s to complete the dispersion. In the last treatment (T_6), 55.7 g of SDM was blended and samples were stored at 25 ± 2 °C for 15 days. The remaining fortified mayonnaise samples were placed at 4 ± 0.5 °C in the refrigerator for further use.

2.5. Oxidative Stability and FAs Composition of Fortified Mayonnaise. *2.5.1. PV.* The PV of experimental samples was calculated using an iodometric titration-based standard Cd 8b-90 method,[25] with some modifications. A mixture of chloroform and acetic acid (2:3, v/v) (Sigma-Aldrich, St. Louis, MO, USA) was prepared at 25 ± 2 °C. Then, 0.2 g of the experimental product sample with 0.5 mL solution of potassium iodide (Sigma-Aldrich) was dissolved in the previously prepared solution and incubated for 3 to 4 min. Then, 30 mL of distilled water was added to the mixture, and the mixture was gently stirred for 1 min. After stirring, 0.5 mL of starch indicator solution (1%) was gently mixed for 1 min, and the solution was titrated with the addition of 0.001 N sodium thiosulfate (Sigma-Aldrich) until its color changed to purple.

2.5.2. FFAs. The concentration of FFAs in experimental product samples was estimated using a standard method Ca 5a-40 of AOCS.[26] In this method, 1 g of the fortified mayonnaise sample was added into a mixture of 25 mL of ethyl alcohol and 50 μL of the phenolphthalein indicator (Sigma-Aldrich). Afterward, the mixture was titrated with 0.01 N NaOH (Sigma-Aldrich) until its color changed to a faint, permanent pink.

2.5.3. FAs Composition. Methyl esters of FAs were estimated using a gas chromatograph (GC) device (model 7890-B, Agilent Technologies, Santa Clara, CA, USA), as reported by Rahim et al.[14] Briefly, the ester of experimental product samples was also evaluated by a GC device using a standard method no. Ce 1f-96, as presented in AOCS.[27] The gas flow velocity and temperature were modified from 20 to 25 mL per min at 185 °C to calculate the FAs composition of the fortified mayonnaise samples. This technique was particularly applied to evaluate the FAs composition of the experimental product samples. The FAs profile was used to measure the peak value by calculating the amount percentage.

2.6. Sensory Analysis of the Experimental Product. Sensory analysis of experimental product samples was conducted by well-trained evaluators through a 9-point

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Table 1. Impact of SDM Fortification and Storage Conditions on ALA Content of Mayonnaise[a]

storage days	ALA (%)						
	T_0	T_1	T_2	T_3	T_4	T_5	T_6
0	0.34 ± 0.18^{Ag}	2.31 ± 0.39^{Aa}	0.39 ± 0.19^{Af}	1.91 ± 0.27^{Ad}	2.22 ± 0.33^{Ab}	0.49 ± 0.16^{Ae}	1.77 ± 0.26^{Ac}
5	0.31 ± 0.17^{Ag}	2.28 ± 0.37^{Aa}	0.38 ± 0.18^{Af}	1.87 ± 0.26^{Ad}	2.17 ± 0.32^{Bb}	0.44 ± 0.16^{Be}	1.72 ± 0.25^{Bc}
10	0.28 ± 0.15^{Be}	2.24 ± 0.34^{Ba}	0.35 ± 0.16^{Ad}	1.84 ± 0.24^{Bc}	2.14 ± 0.32^{Bb}	0.38 ± 0.15^{Bd}	1.67 ± 0.24^{Cd}
15	0.25 ± 0.12^{Bf}	2.20 ± 0.33^{Ba}	0.33 ± 0.15^{Be}	1.80 ± 0.22^{Bc}	2.09 ± 0.31^{Cb}	0.34 ± 0.14^{Ce}	1.60 ± 0.23^{Dd}

[a]ALA, alpha-linolenic acid; T_0, controlled formulation of mayonnaise; T_1, incorporating chia seed oil (CSO); T_2, incorporating fish oil (FO); T_3, incorporating blend of chia and fish oil; T_4, incorporating the SDM of CSO; T_5, incorporating the SDM of FO; T_6, incorporating the SDM of chia and fish oil blend; means with different superscripts, uppercase letters for columns, and lowercase letters for rows that indicated significant difference ($p \leq 0.05$).

Table 2. Impact of SDM Fortification and Storage Conditions on EPA Content of Mayonnaise[a]

storage days	EPA (%)						
	T_0	T_1	T_2	T_3	T_4	T_5	T_6
0	0.031 ± 0.11^{Ad}	0.030 ± 0.11^{Ad}	0.68 ± 0.19^{Aa}	0.48 ± 0.13^{Ac}	0.027 ± 0.10^{Ad}	0.61 ± 0.17^{Ab}	0.44 ± 0.13^{Ac}
5	0.028 ± 0.10^{Ae}	0.026 ± 0.10^{Ae}	0.66 ± 0.17^{Aa}	0.45 ± 0.13^{Ac}	0.023 ± 0.10^{Af}	0.58 ± 0.16^{Ab}	0.41 ± 0.12^{Ad}
10	0.024 ± 0.10^{Be}	0.022 ± 0.10^{Be}	0.62 ± 0.17^{Ba}	0.43 ± 0.13^{Bc}	0.020 ± 0.10^{Be}	0.53 ± 0.15^{Bb}	0.38 ± 0.12^{Bd}
15	0.021 ± 0.10^{Be}	0.019 ± 0.10^{Be}	0.58 ± 0.16^{Ba}	0.41 ± 0.12^{Bc}	0.017 ± 0.09^{Be}	0.49 ± 0.14^{Cb}	0.35 ± 0.12^{Bd}

[a]EPA, eicosapentaenoic acid; T_0, controlled formulation of mayonnaise; T_1, incorporating chia seed oil (CSO); T_2, incorporating fish oil (FO); T_3, incorporating blend of chia and fish oil; T_4, incorporating the SDM of CSO; T_5, incorporating the SDM of FO; T_6, incorporating the SDM of chia and fish oil blend; means with different superscripts, uppercase letters for columns, and lowercase letters for rows that indicated significant difference ($p \leq 0.05$).

hedonic scale. Ten faculty members were selected for their sensory attributes. The sensory scoring for color, off-flavor, and overall acceptability evaluation was characterized as "1 = disliked extremely" to "9 = liked extremely" reported by Meilgaard et al.[28] The fortified mayonnaise samples were characterized with four secret numeric numbers and offered to the trained panelists in random order. The assessors were requested to rate their scores for sensory evaluation according to the observations that they expected from coded experimental product samples.

2.7. Statistical Analysis. Statistix version 8.1 (analytical software, Tallahassee, Florida, USA) was used for data analysis. This study was planned in a completely random design, with every treatment accomplished in triplicate. To calculate the impact of SDM supplementation and storage for 15 days, two-way ANOVA was used for the evaluation of the significant difference ($p \leq 0.05$).

3. RESULTS AND DISCUSSION

3.1. Characteristics of Fortified Mayonnaise. *3.1.1. FAs Composition.* The FAs compositions such as ALA, EPA, and DHA of experimental product samples are described in Tables 1 to 3. In this study, the experimental product samples were prepared by various treatments and stored for 15 days. The value of ALA contents in the control samples was estimated to be $0.34 \pm 0.18\%$ at 0 day, and the amount of ALA reduced significantly to $0.31 \pm 0.17\%$ after 5 days, $0.28 \pm 0.15\%$ after 10 days, and $0.25 \pm 0.12\%$ after 15 days, respectively. A similar trend of ALA samples was observed in T_1 ($2.31 \pm 0.39\%$) at 0 day, $2.28 \pm 0.37\%$ after 5 days, and after 15 days $2.20 \pm 0.33\%$. The results of T_1 concluded that the addition of CSO to the experimental product samples improved the content of ALA. Moreover, the T_2 results indicated that the ALA content was not increased because the FO did not contain the ALA content. The ALA content was improved compared to T_0, and the effect of storage conditions was nonsignificant in T_3. In addition, T_4 showed that the ALA content in samples at 0 day $2.22 \pm 0.33\%$ was significantly reduced to the T_2 ($2.31 \pm 0.39\%$). In T_5, the SDM of FO were not affected by the ALA values as compared to other treatments. In the final treatment (T_6), the content of ALA was improved in the experimental product samples after additional SDM of chia and fish oil mixtures compared to the control treatment. The results of T_2 and T_5 concluded that the ALA content was increased in the experimental product samples (Table 1).

The effects of EPA on SDM fortification and storage conditions of experimental product samples are shown in Table 2. The results revealed that the value of EPA contents in the control samples was calculated to be $0.031 \pm 0.11\%$ at 0 day, and the amount of EPA reduced significantly to $0.028 \pm 0.10\%$ after 5 days, $0.024 \pm 0.10\%$ after 10 days, and $0.021 \pm 0.10\%$ after 15 days, respectively. A similar trend of EPA samples was observed in T_1 ($0.030 \pm 0.11\%$) at 0 day, $0.026 \pm 0.10\%$ after 5 days, and after 15 days $0.019 \pm 0.10\%$. The T_2 results indicated that the EPA content was significantly increased due to the addition of FO associated with the other treatments. The results of T_2 concluded that the addition of FO to the experimental product samples improved the content of EPA. Moreover, the T_1 and T_4 results indicated that the EPA content was not increased because the CSO did not contain the EPA content. In T_3, the EPA content was improved as compared to the control sample, and the effect of storage on the EPA contents was not greater in the experimental product samples. In addition, T_4 showed that the EPA content in samples at 0 day $0.027 \pm 0.10\%$ was close to controlled and T_1 treatment. In T_5, the SDM of FO improved the EPA values as compared to the T_0, T_1, T_2, T_3, and T_4. In the final treatment (T_6), the content of EPA was improved in the experimental product samples after additional SDM of chia and fish oil mixtures compared to the control treatment. The results of all treatments concluded that the EPA content was increased after the addition of FO, chia, and fish oil blend, SDM of FO, and SDM of chia and fish oil in the experimental product samples. The amount of EPA was

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Table 3. Impact of SDM Fortification and Storage Conditions on DHA Content of Mayonnaise[a]

storage days	DHA (%)						
	T_0	T_1	T_2	T_3	T_4	T_5	T_6
0	0.023 ± 0.12^{Ae}	0.029 ± 0.13^{Ad}	1.36 ± 0.19^{Aa}	1.13 ± 0.16^{Ac}	0.026 ± 0.12^{Ad}	1.28 ± 0.18^{Ab}	1.10 ± 0.15^{Ac}
5	0.021 ± 0.12^{Af}	0.027 ± 0.13^{Ae}	1.30 ± 0.18^{Ba}	1.11 ± 0.16^{Ac}	$0.020 \pm 0,12^{Bf}$	1.23 ± 0.17^{Bb}	1.07 ± 0.14^{Ad}
10	0.019 ± 0.11^{Bf}	0.024 ± 0.12^{Be}	1.27 ± 0.18^{Ba}	1.09 ± 0.15^{Bc}	0.017 ± 0.11^{Bf}	1.18 ± 0.16^{Cb}	1.03 ± 0.14^{Bd}
15	0.016 ± 0.11^{Bf}	0.022 ± 0.12^{Be}	1.22 ± 0.17^{Ca}	1.06 ± 0.15^{Bc}	0.015 ± 0.11^{Bf}	1.15 ± 0.16^{Cb}	1.01 ± 0.14^{Bd}

[a]DHA, docosahexaenoic acid; T_0, controlled formulation of mayonnaise; T_1, incorporating chia seed oil (CSO); T_2, incorporating fish oil (FO); T_3, incorporating blend of chia and fish oil; T_4, incorporating the SDM of CSO; T_5, incorporating the SDM of FO; T_6, incorporating the SDM of chia and fish oil blend; means with different superscripts, uppercase letters for columns, and lowercase letters for rows that indicated significant difference ($p \leq 0.05$).

Table 4. Impact of SDM Fortification and Storage Conditions on FFAs of the Experimental Product[a]

storage days	FFAs (%)						
	T_0	T_1	T_2	T_3	T_4	T_5	T_6
0	0.16 ± 0.10^{Bf}	0.24 ± 0.11^{Bd}	0.35 ± 0.13^{Cc}	0.50 ± 0.15^{Ca}	0.20 ± 0.11^{Ce}	0.27 ± 0.12^{Dd}	0.45 ± 0.14^{Bb}
5	0.19 ± 0.11^{Bf}	0.26 ± 0.11^{Be}	0.39 ± 0.13^{Bc}	0.54 ± 0.16^{Ba}	0.22 ± 0.11^{Bf}	0.32 ± 0.13^{Cd}	0.48 ± 0.14^{Bb}
10	0.23 ± 0.11^{Ae}	0.27 ± 0.12^{Ae}	0.42 ± 0.14^{Bc}	0.59 ± 0.16^{Aa}	0.25 ± 0.11^{Be}	0.36 ± 0.13^{Bd}	0.51 ± 0.15^{Bb}
15	0.25 ± 0.11^{Af}	0.30 ± 0.12^{Ae}	0.46 ± 0.14^{Ac}	0.62 ± 0.16^{Aa}	0.29 ± 0.12^{Ae}	0.41 ± 0.14^{Ad}	0.55 ± 0.16^{Ab}

[a]FFAs, free fatty acids; T_0, controlled formulation of mayonnaise; T_1, incorporating chia seed oil (CSO); T_2, incorporating fish oil (FO); T_3, incorporating blend of chia and fish oil; T_4, incorporating the SDM of CSO; T_5, incorporating the SDM of FO; T_6, incorporating the SDM of chia and fish oil blend; means with different superscripts, uppercase letters for columns, and lowercase letters for rows that indicated significant difference ($p \leq 0.05$).

reduced in all treatments during the storage interval. In Table 3, the results specified that the quantity of DHA contents in the control samples was measured to be 0.023 ± 0.12% at 0 day, and the amount of DHA reduced significantly to 0.021 ± 0.12% after 5 days, 0.019 ± 0.11% after 10 days, and 0.016 ± 0.11% after 15 days, respectively. A similar phenomenon of DHA samples was noticed in T_1 (0.029 ± 0.13%) at 0 day, 0.027 ± 0.13% after 5 days, and after 15 days 0.022 ± 0.12%. Moreover, the T_1 and T_4 results indicated that the DHA content was not increased due to the fact that the CSO did not contain the DHA content as associated with the FO of all treatments. The T_2 results showed that the DHA content was significantly increased due to the addition of FO that is an excellent source of DHA. In T_5, the SDM of FO significantly improved the DHA values as compared to T_0, T_1, T_3, and T_4. In the final treatment (T_6), the content of DHA was improved in the experimental product samples after additional SDM of chia and fish oil mixtures associated with the control treatment. The amount of DHA was reduced in all treatments during storage interval.

Our findings are in line with the research work of Rojas et al.[29] In this study, mayonnaise was fortified with the addition of microencapsulated CSO and the results concluded that the formulated mayonnaise contained 5% by weight of PUFAs. In another similar research work, chocolate milk was fortified using microencapsulated CSO at various ratios. The prepared product was stored at room temperature for 120 days, and the results indicated that the characteristics of the formulated food product include 10% encapsulated CSO fresh and after storage (120 days).[30] In addition, the butter was fortified according to the various treatments by the addition of microencapsulated CSO and stored for 3 months. The concentration of LCPUFAs was not significantly different in fresh and 90-day stored butter samples.[31] Venturini et al.[32] reported that the concentration of ALA in fortified cookies by microencapsulated chia oil samples was improved as compared with the control sample. In another research work, a mixture of chia and fish skin oil was used to make an enriched spread product. The results indicated that product samples were enriched with LCPUFAs (CSO and FO, *L. rohita*).[16] Furthermore, Rahmani-Manglano et al.[24] reported that fortified low-fat mayonnaise contained 5% by weight of encapsulated fish oil after 30 days of storage. As indicated, the microencapsulated chia oil and fish oil of edible products have promising health benefits, which have already been proven in various studies. The use of these dietary products was very effective in reducing the risk of many diseases such as chronic cancer, heart disease, and inflammation.[33−35]

3.1.2. FFAs. The effect of FFAs on the SDM fortification and storage conditions of experimental product samples is revealed in Table 4. The final results showed that the amount of FFAs in the T_0 was 0.16 ± 0.10% at 0 day, and the amount of FFAs enhanced significantly to 0.19 ± 0.11% after 5 days, 0.23 ± 0.11% after 10 days, and 0.25 ± 0.11% after 15 days, respectively. A similar phenomenon of FFAs samples was noticed in T_1 (0.24 ± 0.11%) at 0 day, 0.26 ± 0.11% after 5 days, and after 10 days 0.27 ± 0.12%. The T_2 results showed that the FFAs content was significantly increased due to the addition of FO in the experimental product samples. In T_3, the FFAs content was moderately improved as associated with the control sample, and the effect of storage on the FFAs content was increased in the experimental product samples. In the final treatment (T_6), the content of FFAs was reduced in the experimental product samples after additional SDM of the chia and fish oil mixture compared to the T_3. The amount of FFAs was increased in all treatments during the storage interval.

3.1.3. PV. Oils and fats containing PUFAs are mostly oxidized during processing, transportation, preservation, and storage. Lipid oxidation is a major cause of rancidity in the sensory properties of foods like texture, taste, flavor, undesirable odor, and color and also loss in the nutritional properties of the food products. Moreover, it also causes food poisoning, so this reaction should be suppressed in the context of food safety and quality.[36−38]

Table 5. Impact of SDM Fortification and Storage Conditions on PV of the Experimental Product[a]

storage days	PV (meq O_2/kg)						
	T_0	T_1	T_2	T_3	T_4	T_5	T_6
0	1.52 ± 0.12^{Dd}	1.63 ± 0.14^{Dc}	1.90 ± 0.19^{Da}	1.91 ± 0.20^{Ca}	1.51 ± 0.11^{Cd}	1.80 ± 0.17^{Cb}	1.22 ± 0.10^{Be}
5	1.58 ± 0.13^{Ce}	1.69 ± 0.16^{Cd}	1.96 ± 0.21^{Cb}	2.06 ± 0.24^{Ba}	1.56 ± 0.13^{Be}	1.84 ± 0.19^{Cc}	1.25 ± 0.07^{Bf}
10	1.65 ± 0.15^{Bd}	1.76 ± 0.18^{Bc}	2.03 ± 0.23^{Bb}	2.09 ± 0.27^{Ba}	1.60 ± 0.14^{Ae}	1.89 ± 0.20^{Bb}	1.29 ± 0.06^{Af}
15	1.73 ± 0.17^{Ae}	1.81 ± 0.18^{Ad}	2.09 ± 0.28^{Ab}	2.14 ± 0.29^{Aa}	1.64 ± 0.14^{Af}	1.92 ± 0.20^{Ac}	1.32 ± 0.02^{Ag}

[a]PV, peroxide value; T_0, controlled formulation of mayonnaise; T_1, incorporating chia seed oil (CSO); T_2, incorporating fish oil (FO); T_3, incorporating blend of chia and fish oil; T_4, incorporating the SDM of CSO; T_5, incorporating the SDM of FO; T_6, incorporating the SDM of chia and fish oil blend; means with different superscripts, uppercase letters for columns, and lowercase letters for rows that indicated significant difference ($p \leq 0.05$).

Changes in the PV of fortified mayonnaise are described in Table 5. In this study, the value of PV in the control samples was calculated to be 1.52 ± 0.12 meq O_2/kg at 0 day, and the amount of PV increased significantly to 1.58 ± 0.13 meq O_2/kg after 5 days, 1.65 ± 0.15 meq O_2/kg after 10 days, and 1.73 ± 0.17 meq O_2/kg after 15 days, respectively. In all experimental samples, PV was increased in storage conditions. In T_1, a similar trend of PV samples was observed (1.63 ± 0.1 meq O_2/kg) at 0 day, 1.69 ± 0.16 meq O_2/kg after 5 days, and after 15 days 1.81 ± 0.18 meq O_2/kg, respectively. The T_2 of the results indicated that the PV was significantly increased due to the addition of FO compared to the control. In T_5, the SDM of FO reduced the PV of experimental product samples as compared to the T_2. In the final treatment (T_6), the PV of samples was decreased after additional SDM of the chia and fish oil blend compared to the T_3 and control treatment. The results of all treatments concluded that the PV was increased after the addition of SDM of CSO, FO, and their blend in the experimental product samples. In a similar study carried out by Rahmani-Manglano et al.,[24] the oxidative stability of low-fat mayonnaise increased with the addition of glucose syrup-based SDM of sardine FO and the addition of whey protein hydrolysate compared to neat fish oil mayonnaise after 6 weeks of storage at 4 °C. In another similar study conducted by Hermund et al.,[39] the accumulation of electrospray capsules of cod liver oil improved the PV of fortified mayonnaise samples compared to neat FO samples after 21 days of storage. In another research work, the PV of capsule-enriched mayonnaise was significantly higher than mayonnaise enriched with neat cod liver oil after 21 days of storage.[40] Furthermore, the mayonnaise was fortified with encapsulated chia oil. The results of this study show that the enriched mayonnaise was successfully prepared and the encapsulation was effective in protecting the oil from oxidation.[29] Chia oil and fish oil are rich sources of LCPUFAs, which are associated with numerous potential health benefits. Many studies have concluded that the consumption of these omega-enriched food products might help reduce belly fat, lower your risk of mortality in men with heart disease, reduce pain and insulin resistance, develop the brain tissues, and have a positive impact on the endothelial function and is good for the kidney and liver.[24,41,42]

3.1.4. Sensory Analysis. The samples of omega-enriched mayonnaise were evaluated using the 9-point hedonic scale method. The most important sensory attributes are color, off-flavor, and overall acceptability when they are tested by trained sensory panelists. Changes in the mean value of color attributes in omega-enriched mayonnaise are described in Figure 1. In T_1, the average value of the experimental product samples was slightly increased by the accumulation of CSO associated with the control samples. Moreover, T_2 indicated that the color score was not better than that of all treatments due to the significantly yellowish color of the mayonnaise. Similarly, the mean value of the color in T_3 was close to the T_0 and T_1, respectively.Moreover, T_4 showed that the mean value in color samples was 7.4 ± 0.25 at 0 day, 7.2 ± 0.23 after 5 days, 7.0 ± 0.21 after 10 days, and 6.9 ± 0.20 after 15 days was slightly reduced to T_1 treatment and closed to the control samples. In T_5, the SDM of FO increased the color of experimental product samples compared to the T_2. In the final treatment (T_6), the scores of color attributes were improved after additional SDM of chia and fish oil blend compared to the T_3 and control treatment, as shown in Figure 1.

The off-flavor spider chart shows that the scores of the treated samples differed slightly from the control treatment. In Figure 1, the control samples tasted better than the treated samples, T_1 and T_2. T_2 scores were lower due to the fishy taste of FO. The incorporation of chia and fish oil blend in the experimental product indicated better scores than the CSO and FO samples. Furthermore, the SDM samples of the experimental product showed that the scores were better than those of the crude oil and its blend samples. The results concluded that the off-flavor of the samples was also affected by the viscosity of the fortified mayonnaise, as the proliferation of LCPUFAs was affected by the viscosity of the system. The effect of SDM fortification and storage conditions on the overall acceptability of experimental products that were selected for profiling is presented in Figure 1. The results revealed that T_6 gained better scores compared to other treated samples. However, the SDM blend of the chia and fish oil experimental product was overall acceptable.

Rojas et al.[29] observed that mayonnaise samples containing microcapsules of oils (chia seeds, pumpkin seeds, and baru) up to 5 wt % did not differ from control (base mayonnaise) in the sensorial test. Moreover, mayonnaise was fortified with chia oil, which shows good sensory acceptance.[3] Yesiltas et al.[43] reported that FO has not strengthened mayonnaise, which is significantly lower in broken attribute than other samples. Furthermore, a study carried out by Jacobsen et al.[44] concluded that the addition of fish oil showed no significant effect on the sensory properties of mayonnaise. Li Hsieh and Regenstein[45] reported that the sensory quality of fish oil mayonnaise was deodorized during storing at 2 °C for 14 weeks compared to the other treatments. Jeyakumari et al.[46] found that the sensory attributes of microencapsulated fish oil significantly reduced lipid rancidity in the experimental product. In another study, the sensory attributes of fortified mayonnaise with encapsulated fish oil indicated that it had the least overall acceptability by the panel.[47] Furthermore, changes in the score of the enriched spread product were similar to the research work of Ghosh et al.[16] In another study, the oil blend

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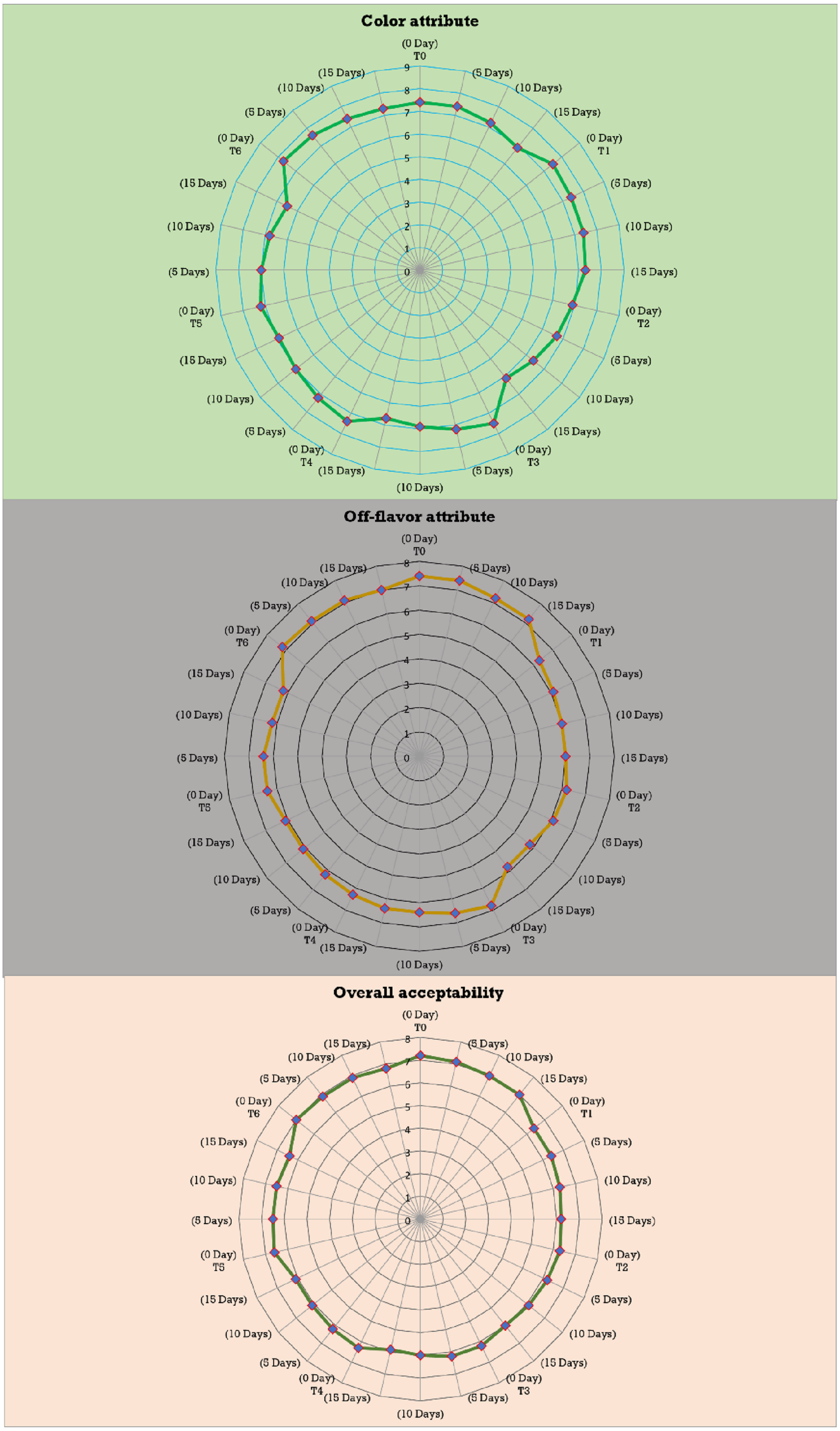

Figure 1. Impact of treatments and storage on the sensory attributes of the experimental product.

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used to make mayonnaise and a storage time of 30 days affected the sensory attributes of fortified mayonnaise in an acceptable range.[48]

4. CONCLUSIONS

ω-3 FAs are essential FAs that our bodies cannot make themselves, so they must get them from functional foods. Therefore, the food processing industries are becoming more interested in the production of ω-3-enriched food products, as consumers and healthcare organizations are increasingly demanding functional foods with a minimum FA loss and high oxidative stability. It is interesting to note that SDM fortification in mayonnaise was acceptable up to a level of 5% by weight, yet fortified mayonnaise with 4% by weight SDM showed a slight decrease in flavor scores than the control sample. All mayonnaise treatments were acceptable within 15 days of storage based on chemical composition and oxidative and sensory evaluation, as well as providing consumers with adequate levels of LCPUFAs.

■ ASSOCIATED CONTENT

Data Availability Statement

Data is contained within the article.

■ AUTHOR INFORMATION

Corresponding Authors

Muhammad Imran − *Department of Food Science, Faculty of Life Sciences, Government College University, Faisalabad 38000, Pakistan*; Email: imran@gcuf.edu.pk

Eliasse Zongo − *Laboratoire de Recherche et d'Enseignement en Santé et Biotechnologies Animales, Université Nazi BONI, Bobo Dioulasso 1091, Burkina Faso*; orcid.org/0000-0001-9885-8301; Email: zongoeliasse@yahoo.fr

Authors

Muhammad Abdul Rahim − *Department of Food Science & Nutrition, Faculty of Medicine and Allied Health Sciences, Times Institute, Multan 60700, Pakistan; Department of Food Science, Faculty of Life Sciences, Government College University, Faisalabad 38000, Pakistan*

Faima Atta Khan − *Department of Food Science, Faculty of Life Sciences, Government College University, Faisalabad 38000, Pakistan; University Institute of Diet & Nutritional Sciences, The University of Lahore, Punjab 40100, Pakistan*

Fahad Al-Asmari − *Department of Food and Nutrition Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa 31982, Kingdom of Saudi Arabia*

Osama F. Mosa − *Public Health Department, Health Sciences College at Lieth, Umm Al-Qura University, Makkah 24231, Saudi Arabia*

Riyadh S. Almalki − *Department of Pharmacology and Toxicology, Faculty of Pharmacy, Umm AL-Qura University, Makkah 21421, Saudi Arabia*

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.3c08807

Author Contributions

M.A.R. and M.I. performed the experiments. F.A.-A. and F.A.K. did conceptualization, funding acquisition, and writing of the original draft. O.F.M. and R.S.A. helped in writing of this manuscript. M.A.R., E.Z., and M.I. helped with the software. M.I. supported the analysis and supervision of the research work. All authors have read and agreed to the published version of the manuscript.

Notes

The authors declare no competing financial interest.

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