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Research Article

OMEGA-3 Fatty Acids Retention, Oxidative Quality, and Sensoric Acceptability of Spray-Dried Flaxseed Oil

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Flaxseed is naturally a rich source of essential omega-3 fatty acid, α-linolenic acid (ALA), which exhibits nearly 57% of its entire fatty acid profile. Oxidation of omega-3 fatty acids during processing and storage results in reduced shelf stability of food products and limited health potentials. Spray-drying is considered a processing technique to shield omega-3 fatty acids from oxidative damage. For the purpose, the extracted flaxseed oil (FSO) together with the emulsifier (flaxseed meal polysaccharide gum) was passed through a mini spray-dryer to prepare spray-dried flaxseed oil (SDFSO) samples. The SDFSO samples for quality were evaluated at 0th, 30th, and 60th days of storage at two different temperatures of 4°C and 25°C, accordingly. The maximum oil protection efficiency was recorded as 90.78% at 160°C. The highest percentage for ALA retention was recorded as 54.7% and 53.9% at 4°C, while the lowest retention was observed as 48.6% and 46.2% at 25°C after 30 and 60 days of storage, respectively. The inlet (160°C) and outlet air temperatures (80°C) were considered as key factors contributing a decline in retention of ALA of the SDFSO samples. The free fatty acid contents of FSO and SDFSO samples reached to their peaks, i.e., 1.22% and 0.75%, respectively, after 60 days of storage at 25°C. The initial peroxide value of FSO (control) was 0.16, which increased to 0.34 (4°C) and 1.10 (25°C) meq/kg O_2 at the end of 60 days storage. The value for malondialdehyde of SDFSO samples was increased from 0.17 (0 day) to 0.34 nmol/g of lipids at 60 days (4°C), and the same increasing trend was observed at 25°C. In the case of color and overall acceptability, the lowest evaluation scores were awarded to FSO samples in comparison to SDFSO samples. Overall, SDFSO possessed improved oxidative quality and can be recommended as a fortifying agent in various functional food products.

1. Introduction

Globally, consumers are more conscious about what they eat and what are beneficial aspects gained from specific ingredients for maintaining good health. Diet-based therapy is a unique prospect to use innovative functional foods. These foods play an outstanding role in promoting health, longevity, and prevention of chronic diseases [1]. In this connection, polyunsaturated fatty acids (PUFAs) are the most important families of omega-3 and omega-6 fatty acids, gaining importance as part of functional food ingredients. As human body cannot synthesize them so they must be present in the diet in ample amounts. These PUFAs such as linolenic acids (ALA), eicosapentaenoic acids (EPA), and docosahexaenoic acids (DHA) have potential health benefits including anti-inflammatory, antimicrobial, antithrombotic, antihypertensive, antiaging, anticancer, and antidiabetic properties [2].

Flaxseed (*Linum usitatissimum* L.) belongs to family *Linaceae*. It has recently grown a great popularity and scientific attention owing to its huge amount of lipid content, increased acceptance by the consumers, and its functional and nutritional values. It is an industrial major crop used for oil and fiber contents. The main benefits of using flaxseed in human nutrition are its very high dietary fiber (28–30%) and abundance of ALA ($C_{18:3}$). Nearly, 80% of flaxseed oil (FSO) is used for the purposes of different industries and remaining 20% is used for edible purposes [3]. Practically, every part of the flaxseed plant is commercially useable, either directly or after processing [4, 5]. Nowadays, FSO is frequently used in food processing industries predominantly in the formulation of products such as cookies and bread recipes, and such products have acquired enormous competence in the market [6]. However, food industries are facing problem of oxidation of these unstable PUFAs during processing and storage [7]. Moreover, the resultant oxidation products such as ketone, aldehydes, and free acids have capability to crosslink to proteins and bind covalently to nucleic acids and ultimately results to enhance aging, carcinogenesis mechanisms, and mutagenesis in the biological system [8]. Thus, besides achieving maximum extraction efficiency of PUFAs enriched oils, it is also crucial to find out an effective way to preserve bioactive contents of the oil [9].

Microencapsulation is now being largely employed for the production of dry edible oil stuffs. It has been documented that microencapsulation prolong the shelf stability of polyunsaturated oils by shielding them from oxidative damage. Microencapsulation of edible oils by powder particles, comprising carbohydrate or proteins is a scientific process followed to protect polyunsaturated oils from oxidation resultantly preserving flavors, aroma, and transport bioactive oils into easily managed dried solids for food supplementation [10–12]. Spray-drying is one of the most commonly used microencapsulation techniques [13, 14]. The associated beneficial health effects of spray-dried PUFAs enriched oils depend on their metabolic digestion and bioavailability [15]. Hence, it is much important to discuss and evaluate the *in vitro* digestion models of spray-dried encapsulated oils under various gastrointestinal conditions [16]. Therefore, the mandate of the study was to enlighten the effects of spray-drying conditions on retention of omega-3 fatty acids in FSO samples and evaluation of spray-dried flaxseed oil (SDFSO) samples for oxidative quality and sensoric acceptability.

2. Materials and Methods

2.1. Preliminary Processing of Oilseed Material. Flaxseeds (*Linum usitatissimum* L.) cultivar *Chandani* obtained from the Institute for Oilseed Research, Faisalabad, Punjab, Pakistan, were cleaned to take out dirt and other foreign substances.

2.2. Oil Extraction. Raw flaxseeds were weighed by using electronic scales (model Kern 440-35N) and were processed with the mini oil presser (model 6YL-550, with 2-3 kg/hour capacity) for oil extraction.

2.3. Polysaccharides Gums (PSG) Extraction. The flaxseed meal samples were operated using ultrasound-assisted technology (model VCX 750, Sonics & Materials, Inc., USA) to derived polysaccharide gum (PSG) [17]. The extracted solutions of PSG were filtered over a 40-mesh screen and precipitated with two volumes of 95% ethanol. The separation of PSG was done by centrifugation, and further dried in a benchtop laboratory freeze dryer.

2.4. Emulsion Preparation. The PSG as wall materials was added to distilled water at a temperature of 25°C. The combination was agitated until it completely dissolved. Addition of FSO to the wall material solution was fixed. Emulsions were formed using a homogenizer operating at 18000 rpm for 5 min [18].

2.5. Spray-Drying Process. The oil microcapsules enriched with omega-3 fatty acids were prepared with a mini spray-dryer (Toption Lab Spray Dryer, Xi'an, China). The graphic diagram for the lab-scale spray-dryer is demonstrated in Figure 1.

In the present study, spray-drying operating factors such as the inlet air temperature (120, 140, and 160°C), feed flow rate (200, 250, and 300 mL/hr), atomization speed (12000, 16000, and 20000 rpm), and the outlet air temperature (60, 70, and 80°C) were optimized as given in Table 1. The FSO microcapsules were collected in a single cyclone separator and stored at 25°C and 4°C, respectively, after packaging for successive 2 months.

2.6. Encapsulation Efficiency. The encapsulation efficiency of SDFSO samples was investigated by adopting the procedure of Bae and Lee [19]. Hexane (15 mm) was introduced into a glass container, containing 1.5 g of dried oil powder. The container was shaken to extract free oil. Subsequently, Whatman No. 1 filter paper was used for filtration. Then with 20 mL of hexane, the remaining powder on the filter was washed off. The leftover solvent was put to evaporate. The amount of surface oil was calculated by measuring the difference in mass between the early clean flask and the other one containing the residual oil extract. The total amount of FSO in microcapsules was computed using numerical expression [19].

$$\mathrm{EE}\,(\%) = \frac{(\text{total amount of oil} - \text{surface oil})}{\text{total amount of oil}} * 100. \quad (1)$$

2.7. ALA Fatty Acid Profile of SDFSO Samples. The ALA fatty acid profile of FSO and SDFSO samples was recorded by gas chromatograph equipped with a column and flame ionization detector (FID). Briefly, the fatty acids were transformed to methyl esters using acid catalyzed methanolysis method [20]. The transport gas was nitrogen with a flowing speed of 1 mL/min. The temperature of the injection port and detector was set at 170°C and 240°C, respectively. The estimation of ALA percentage was calculated by measuring the respective peak area.

2.8. Free Fatty Acids of FSO and SDFSO Samples. Free fatty acid content of FSO and SDFSO samples was measured by

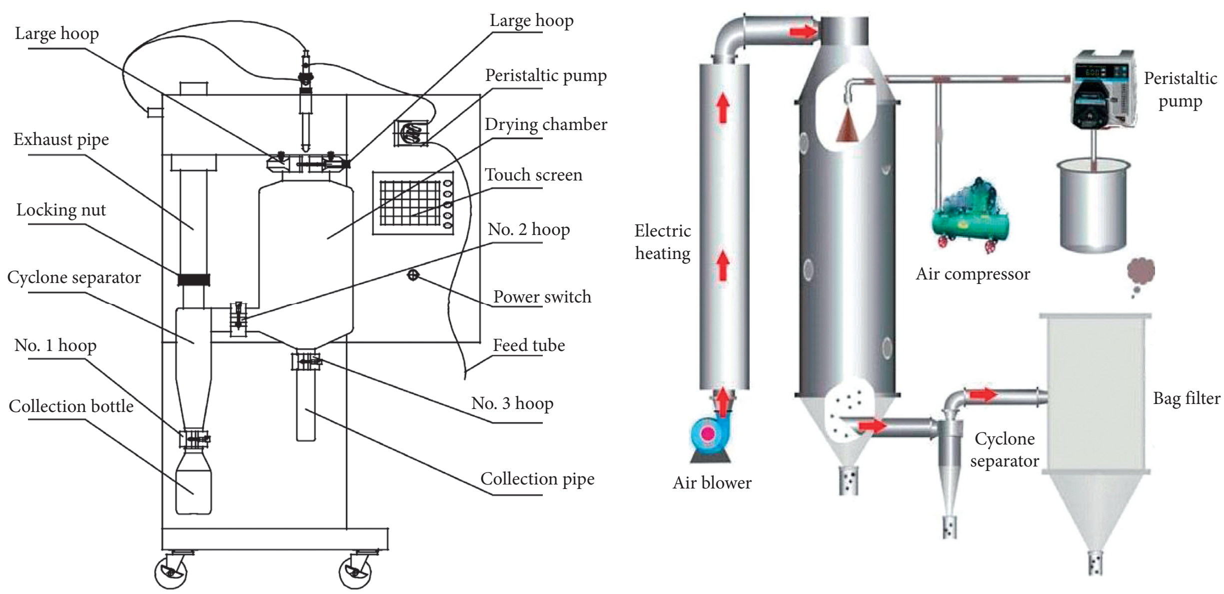

Figure 1: The schematic diagram of the lab-scale spray-dryer.

Table 1: Coded and actual levels of independent variables for optimization of response factors as determined by Box–Behnken design.

Independent variables	Units	Coded levels −1	0	+1
Inlet air temperature	°C	120	140	160
Feed flow rate	mL/hr	200	250	300
Atomization speed	rpm	12000	16000	20000
Outlet air temperature	°C	60	70	80

titrating the SDFSO samples dissolved in alcohol against sodium hydroxide (NaOH) to a specific end point by procedures described in the AOCS method no. Ca 5a-40 [20].

2.9. Oxidative Stability of SDFSO Samples. The peroxide value for FSO and SDFSO samples was determined following the method elaborated by the AOCS [20] method no. Cd 8–53. The malondialdehyde test was used to calculate the lipid peroxidation according to Kirk and Sawyer [21] method with some modifications. The conjugated double bonds were noted using European Communities official methods [22].

2.10. Sensoric Acceptability of SDFSO Samples. Experienced and untrained assessors carried out the preference for sensoric acceptability of FSO and SDFSO samples according to the instructions given by Meilgaard et al. [23]. Informed consent form was explained for risks and benefits of participation, and each participating judge gave the written consent prior to the study. The brief definitions of sensoric attributes such as color, off-flavor, and overall acceptability regarding FSO and SDFSO samples were described each time to participating judges. Samples were presented to participating judges in sensory booths under controlled conditions and white lighting. The order of presentation was balanced to avoid carry over effects. Each participating judge received the FSO and SDFSO samples assigned with random three-digit code numbers. Each participating judge was asked to list preference on a 9 cm comparison line (1 = extremely dislike to 9 = extremely like) for color and overall acceptability parameter while (1 = extremely like to 9 = extremely dislike) for off-flavor sensoric attribute. The sensoric analysis was performed at different storage intervals for experimental FSO and SDFSO samples.

2.11. Statistical Design and Data Analysis. The Box–Behnken design of response surface methodology was applied to determine the optimized values of the inlet air temperature, feed flow rate, atomization speed, and the outlet air temperature for spray-drying process parameters. The response data of FSO and SDFSO obtained for each treatment were subjected to a statistical analysis using software package (MATLAB), according to the described method [24] for determination of mutual effects. The average of the three runs was reported as the measured value with the standard deviation. The analysis of samples for storage stability and sensoric acceptability was accomplished in triplicate and significant differences among the means were calculated at a 5% probability level.

3. Results and Discussion

3.1. Encapsulation Efficiency of SDFSO Samples. Encapsulation efficiency is the degree of oil protection, and it depends on numerous factors. The most crucial factors defining encapsulation efficiency are the wall material and inlet air temperature of a spray-dryer [25]. The temperature employed for drying of FSO in this study were, 120, 140, and 160°C. The maximum oil protection efficiency was recorded as 90.78% at 160°C and the lowest was observed as 85.27% at 120°C as shown in Figure 2. The high inlet air temperature

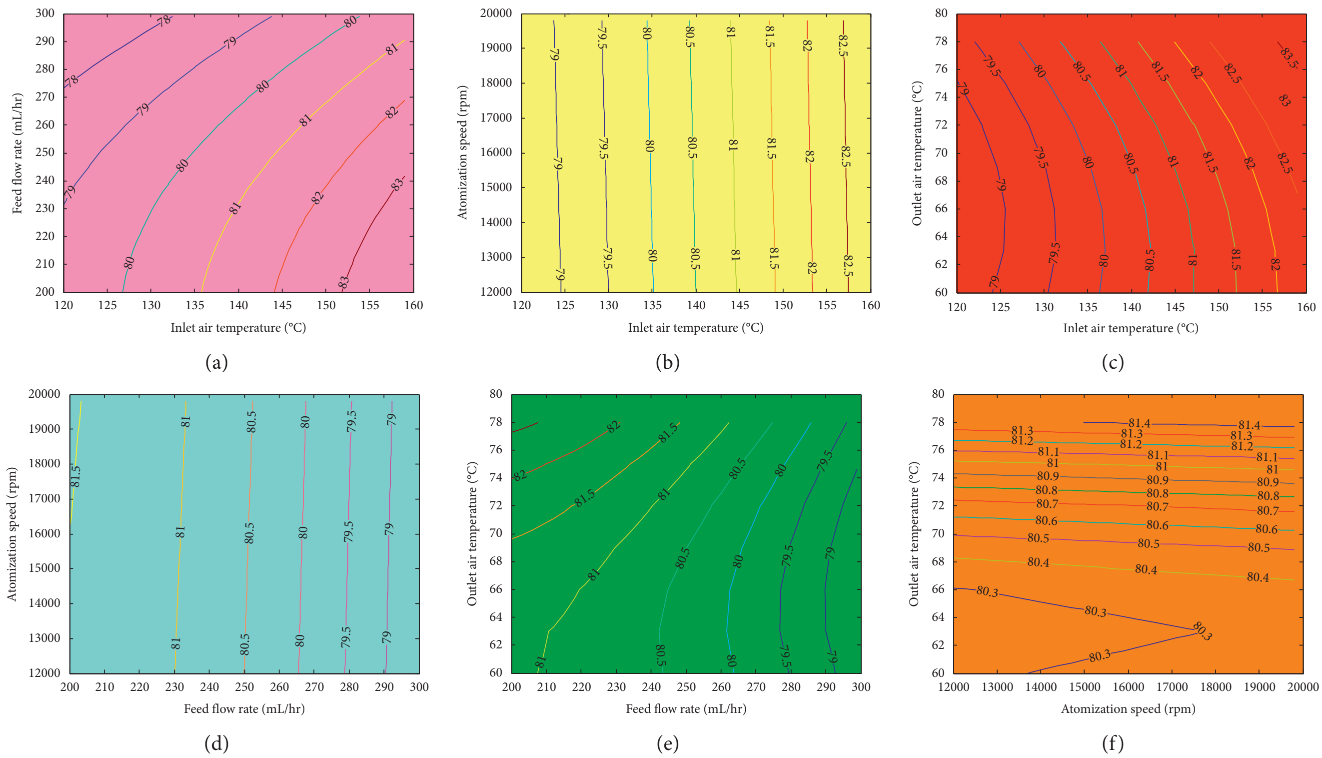

Figure 2: Contour plots for the mutual interaction effect of spray-drying conditions on the encapsulation efficiency of flaxseed oil samples.

may have contributed towards high encapsulation efficiencies that were observed during this research. In a trial conducted by Aghbashlo et al. [26], increased inlet temperatures may contribute to swift formation of the microcapsules and a stable membrane that minimized the migration of oil to the surface of encapsulated microcapsules. Moreover, the wall material used for encapsulation, flaxseed PSG, may also be responsible for its higher viscosity and contributes for the high efficiency [18]. This outstanding efficiency noticed in this study may also be related to the better stability revealed by the emulsion prepared with the flaxseed PSG as wall material [27]. This coating material provided shield to the emulsion droplets and prevented from disruption and disintegration during the atomization process. It is also documented that starch or carbohydrate-based materials are great in film forming as compared to proteins, which can certainly influence the microencapsulation process and avoid oil migration to the powder surface [28].

3.2. Retention Yield of ALA in FSO and SDFSO Samples. In current research, effect of spray-drying conditions, i.e., inlet and outlet air temperatures, atomization pressure, and feed flow rate, was examined on ALA retention in SDFSO. The oil extracted from flaxseeds is naturally a rich source of PUFAs, especially ALA, which exhibits nearly 57% of its entire fatty acid profile. Additionally, ALA is also precursor for long chain (omega-3) fatty acids like EPA and DHA. This high level of ALA fatty acid contents of FSO lets its attribution to functional food, which means besides its nutritional significance, its consumption may also have positive health effects [29]. Moreover, numerous studies have also proven their protective role against inflammation and cardiovascular disease [30]. However, the relatively short shelf stability of PUFAs rich oils limits their application in various food formulations.

Hence, in this respect, the retention of ALA in SDFSO was investigated in 30 samples at three stages, i.e., in freshly prepared samples at 0, 30, and 60th day of storage at two different temperatures of 4°C and 25°C, accordingly as shown in Table 2. The initial ALA content in FSO (control) samples was $57.05 \pm 0.34\%$. There was no significant difference among the ALA contents of FSO and SDFSO samples at 0 days. It is evident from the results that the ALA contents of SDFSO samples were not stable instead they fluctuate under varied interval and conditions of storage. The highest percentage for ALA retention was recorded as $54.72 \pm 0.86\%$ and $53.95 \pm 0.76\%$ at 4°C (spray-drying run 9), while the lowest retention percentage for SDFSO samples was observed as $48.63 \pm 0.64\%$ and $46.25 \pm 0.56\%$ at 25°C after 30 and 60 days of storage, respectively. Moreover, the control FSO samples showed the minimum retention of ALA contents ($44.12 \pm 0.50\%$) at 25°C after 60 days of storage. The inlet and outlet air temperatures were considered as key factors contributing decline in retention of ALA of SDFSO (Figure 3). Moreover, ALA content was decreased significantly when stored at higher temperature as compared to lower temperature under different storage intervals.

Hence, it may be concluded that the SDFSO samples stored at lower temperature are more stable as compared to

Table 2: Impact of spray-drying conditions on alpha-linolenic fatty acids retention in flaxseed oil dried powder at different days and storage intervals.

Spray-dryer process run	Independent variables				Alpha-linolenic fatty acids (% of total fatty acids)				
	Inlet air temperature (°C)	Feed flow rate (mL/hr)	Atomization speed (rpm)	Outlet temperature (°C)	0 days	Storage at temperature 4°C		Storage at temperature 25°C	
						30 days	60 days	30 days	60 days
1	140 (0)	300 (+1)	16000 (0)	60 (−1)	54.30 ± 0.95^{a}	53.72 ± 0.92^{ab}	51.58 ± 0.72^{bc}	51.32 ± 0.65^{bc}	47.62 ± 0.55^{de}
2	140 (0)	250 (0)	12000 (−1)	60 (−1)	54.82 ± 0.90^{a}	53.12 ± 0.89^{ab}	52.95 ± 0.75^{b}	52.52 ± 0.69^{b}	47.84 ± 0.67^{de}
3	140 (0)	200 (−1)	16000 (0)	80 (+1)	51.35 ± 0.85^{bc}	50.78 ± 0.79^{c}	49.84 ± 0.69^{cd}	48.24 ± 0.60^{d}	47.56 ± 0.59^{de}
4	120 (−1)	200 (−1)	16000 (0)	70 (0)	53.71 ± 0.79^{ab}	52.94 ± 0.68^{b}	51.34 ± 0.59^{bc}	51.12 ± 0.52^{bc}	48.11 ± 0.51^{d}
5	160 (+1)	300 (+1)	16000 (0)	70 (0)	51.92 ± 0.84^{bc}	50.84 ± 0.80^{c}	49.92 ± 0.75^{cd}	48.98 ± 0.68^{d}	47.86 ± 0.59^{de}
6 (C_1)	140 (0)	250 (0)	16000 (0)	70 (0)	53.04 ± 0.91^{ab}	52.35 ± 0.81^{b}	51.54 ± 0.75^{bc}	51.35 ± 0.61^{bc}	$47.52.\pm 0.69^{de}$
7	120 (−1)	250 (0)	16000 (0)	80 (+1)	51.44 ± 0.84^{bc}	50.89 ± 0.76^{c}	49.74 ± 0.68^{cd}	49.25 ± 0.59^{cd}	46.38 ± 0.54^{e}
8 (C_2)	140 (0)	250 (0)	16000 (0)	70 (0)	53.08 ± 0.74^{ab}	52.35 ± 0.68^{b}	51.45 ± 0.59^{bc}	50.92 ± 0.57^{c}	47.32 ± 0.51^{de}
9	140 (0)	200 (−1)	16000 (0)	60 (−1)	55.07 ± 0.96^{aa}	54.72 ± 0.86^{a}	53.95 ± 0.76^{ab}	52.52 ± 0.67^{b}	48.15 ± 0.63^{d}
10	160 (+1)	250 (0)	16000 (0)	60 (−1)	54.20 ± 0.81^{a}	53.15 ± 0.75^{ab}	52.19 ± 0.65^{b}	51.65 ± 0.58^{bc}	47.98 ± 0.52^{de}
11	160 (+1)	250 (0)	12000 (−1)	70 (0)	52.40 ± 0.71^{b}	51.65 ± 0.65^{bc}	50.22 ± 0.58^{c}	49.81 ± 0.56^{cd}	46.85 ± 0.49^{e}
12	120 (−1)	250 (0)	12000 (−1)	70 (0)	53.50 ± 0.86^{ab}	52.64 ± 0.82^{b}	51.33 ± 0.79^{bc}	51.10 ± 0.68^{bc}	47.46 ± 0.57^{de}
13	140 (0)	200 (−1)	20000 (+1)	70 (0)	53.10 ± 0.92^{ab}	50.84 ± 0.81^{c}	50.45 ± 0.74^{c}	50.11 ± 0.61^{c}	48.16 ± 0.55^{d}
14	120 (−1)	250 (0)	16000 (0)	60 (−1)	55.01 ± 0.76^{aa}	53.65 ± 0.75^{ab}	52.61 ± 0.67^{b}	52.31 ± 0.58^{b}	49.61 ± 0.50^{cd}
15 (C_3)	140 (0)	250 (0)	16000 (0)	70 (0)	53.16 ± 0.82^{ab}	52.75 ± 0.71^{b}	51.75 ± 0.65^{bc}	51.22 ± 0.59^{bc}	48.45 ± 0.48^{d}
16	120 (−1)	300 (+1)	16000 (0)	70 (0)	53.11 ± 0.79^{ab}	52.75 ± 0.68^{b}	51.74 ± 0.57^{bc}	51.12 ± 0.54^{bc}	47.33 ± 0.45^{de}
17	140 (0)	250 (0)	12000 (−1)	80 (+1)	51.15 ± 0.92^{bc}	50.22 ± 0.82^{c}	49.32 ± 0.77^{cd}	48.96 ± 0.69^{d}	46.78 ± 0.56^{e}
18 (C_4)	140 (0)	250 (0)	16000 (0)	70 (0)	53.18 ± 0.84^{ab}	52.62 ± 0.74^{b}	51.73 ± 0.69^{bc}	51.23 ± 0.55^{bc}	48.98 ± 0.49^{d}
19	140 (0)	300 (+1)	16000 (0)	80 (+1)	50.60 ± 0.74^{c}	49.91 ± 0.71^{cd}	48.55 ± 0.65^{d}	47.95 ± 0.57^{de}	46.51 ± 0.52^{e}
20	160 (+1)	250 (0)	16000 (0)	80 (+1)	50.31 ± 0.93^{c}	50.02 ± 0.88^{c}	49.32 ± 0.78^{cd}	48.63 ± 0.64^{d}	46.25 ± 0.56^{e}
21	140 (0)	300 (+1)	12000 (−1)	70 (0)	52.70 ± 0.90^{b}	51.91 ± 0.85^{bc}	50.73 ± 0.75^{c}	49.99 ± 0.62^{cd}	47.67 ± 0.59^{de}
22	120 (−1)	250 (0)	20000 (+1)	70 (0)	53.21 ± 0.83^{ab}	52.52 ± 0.78^{b}	51.43 ± 0.66^{bc}	50.43 ± 0.58^{c}	48.57 ± 0.48^{d}
23	140 (0)	250 (0)	20000 (+1)	80 (+1)	50.80 ± 0.78^{c}	49.95 ± 0.75^{cd}	48.11 ± 0.68^{d}	47.65 ± 0.60^{de}	46.74 ± 0.55^{e}
24	140 (0)	300 (+1)	20000 (+1)	70 (0)	52.40 ± 0.86^{b}	51.33 ± 0.77^{bc}	50.64 ± 0.70^{c}	50.18 ± 0.59^{c}	47.45 ± 0.51^{de}
25	140 (0)	250 (0)	20000 (+1)	60 (−1)	54.50 ± 0.96^{a}	53.51 ± 0.87^{ab}	52.01 ± 0.81^{b}	51.84 ± 0.77^{bc}	48.34 ± 0.68^{d}
26	160 (+1)	250 (0)	20000 (+1)	70 (0)	52.10 ± 0.91^{b}	51.22 ± 0.86^{bc}	50.21 ± 0.79^{c}	49.73 ± 0.66^{cd}	46.83 ± 0.57^{e}
27	160 (+1)	200 (−1)	16000 (0)	70 (0)	52.60 ± 0.84^{b}	51.00 ± 0.74^{bc}	50.04 ± 0.64^{c}	49.64 ± 0.60^{cd}	47.14 ± 0.51^{de}
28	140 (0)	200 (−1)	12000 (−1)	70 (0)	53.41 ± 0.77^{ab}	52.54 ± 0.69^{b}	51.23 ± 0.61^{bc}	50.92 ± 0.57^{c}	46.96 ± 0.49^{e}
29 (C_5)	140 (0)	250 (0)	16000 (0)	70 (0)	53.08 ± 0.81^{ab}	50.91 ± 0.73^{c}	49.21 ± 0.63^{cd}	48.75 ± 0.61^{d}	47.33 ± 0.55^{de}
30 (C_6)	140 (0)	250 (0)	16000 (0)	70 (0)	53.24 ± 0.93^{ab}	52.65 ± 0.88^{b}	51.54 ± 0.78^{bc}	51.11 ± 0.64^{bc}	47.84 ± 0.53^{de}

^{C1,C2,C3,C4,C5,C6}Spray-drying process at center points. Experimental model = Box–Behnken design. Total number of spray-drying treatments = 30. Number of replicates = 03. $^{a-e}$Values with similar letters show homogenous groups within the row and column ($p > 0.05$).

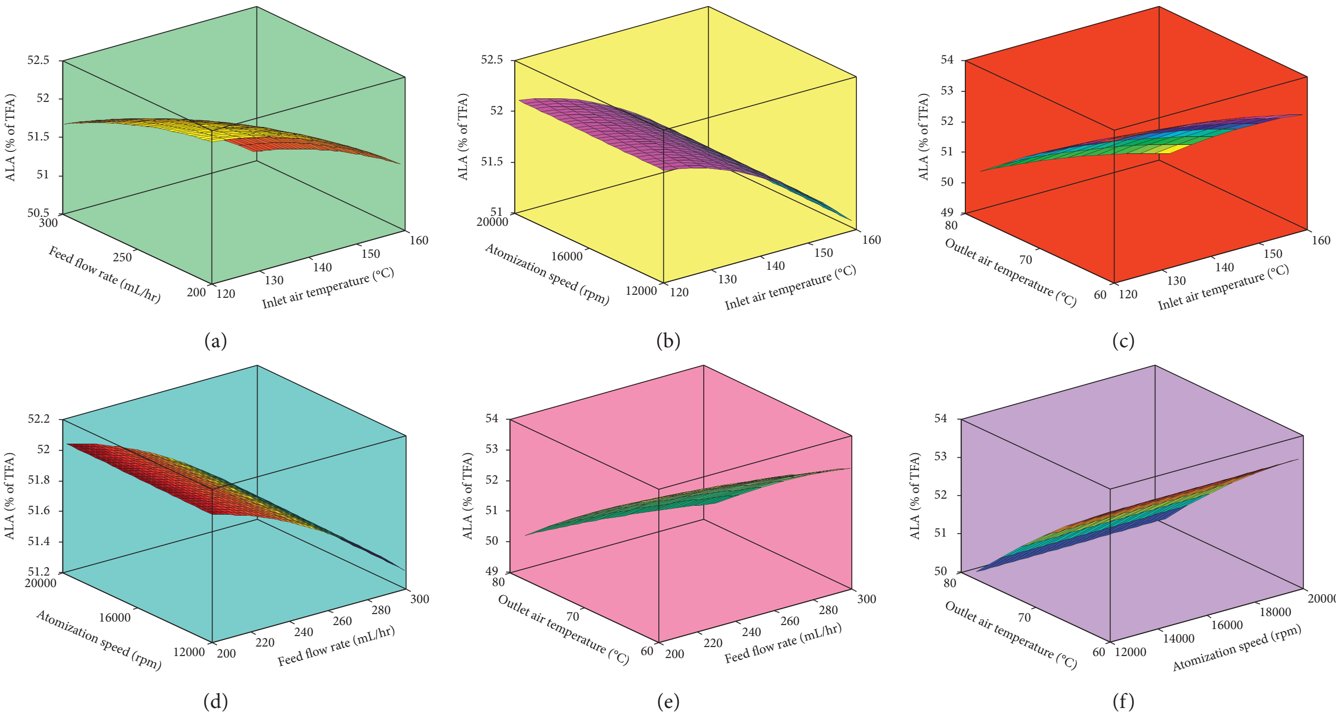

Figure 3: Response surfaces for the mutual interaction effect of spray-drying conditions on the alpha-linolenic acids (ALA) retention in flaxseed oil samples.

others stored at higher temperature. However, the values for ALA contents did not changed significantly and remained in the acceptable limits, showing the effectiveness of the spray-drying encapsulation technique. Similar findings are also reported by Javed et al. [31] as they produced spray-dried PUFAs enriched egg powder, and stated that the PUFAs stayed stable up to two months when stored at 4°C as contrarily some decline was observed in samples stored at high temperature.

3.3. Free Fatty Acids (FFAs) Contents of FSO and SDFSO Samples. The influence of spray-dryer and storage conditions on free fatty acids (FFAs) contents of SDFSO have been shown in Table 3. The FFAs contents of FSO and SDFSO samples reached to their peaks, i.e., $1.22 \pm 0.13\%$ and $0.75 \pm 0.07\%$, respectively, after 60 days of storage at 25°C. The increasing pattern shows that lipid oxidation has enhanced with storage. It is evident from the results that the SDFSO samples stored for 30 days at lower temperature are quite stable than stored at higher temperature for 60 days. The values for FFAs contents of all the SDFSO samples were well below the limit of 2%, which is considered a trigger of rancidity. The oxidation of PUFAs in foods generates FFAs, aldehydes, hydroperoxides, and polymeric substances that end up in adverse health consequences and possibly leading to some chronic illnesses such as cardiovascular, cancer, and neurological disorders [32].

3.4. Oxidative Stability of SDFSO Samples. In the current study, the progression of lipid oxidation in SDFSO was monitored by measuring the formation of various oxidation products like, peroxide value (PV), malondialdehyde (MDA), and conjugated dienes (CDs). Encapsulated FSO in the powder form is more stable to oxidative damage when compared to free oil. The initial PV of FSO (control) was 0.16 ± 0.03, which increased to 0.34 ± 0.05 (4°C) and 1.10 ± 0.07 (25°C) meq/kg O_2 at the end of 60 days storage. According to Table 4, the PV of SDFSO samples ranged from 0.16 ± 0.03 to 0.20 ± 0.05 meq/kg O_2 along with change in the inlet air temperature of 120 to 160°C. The results showed that there were no significant differences between PV of SDFSO samples and control on initial days of the experimental trial; however, as the storage period proceeded from 30 to 60 days, the PV of SDFSO samples was also increased from 0.25 ± 0.06 to 0.30 ± 0.07 at temperature of 4°C, while the PV was noted as 0.37 ± 0.07 and 0.62 ± 0.07 meq/kg O_2 when stored at 25°C for similar storage period. In the present investigation, the data further revealed a two-fold increase in PV for the FSO samples as compared to the SDFSO samples. In general, higher oil loads led to higher peroxide values. According to the previous observations by different researchers, the reason for increasing PV during storage may be due to the high oil load on the surface of SDFSO, leading to low encapsulation efficiency [27]. This can lead to poor protection of dried oil from lipid oxidation. This nonencapsulated oil on the surface, when comes in contact with oxygen becomes more susceptible to lipid oxidation than the encapsulated oil. According to the findings of Andersen et al. [33], when the oil is subjected to encapsulation into a wall matrix, some oil particles may oxidize slowly whilst, others may oxidize more rapidly owing to the variability in the degree of encapsulation.

Table 3: Impact of spray-drying conditions on free fatty acids in flaxseed oil dried powder at different days and storage intervals.

Spray-dryer process run	Independent variables: Inlet air temperature (°C)	Feed flow rate (mL/hr)	Atomization speed (rpm)	Outlet temperature (°C)	Free fatty acids (%): 0 days	Storage at temperature 4°C: 30 days	Storage at temperature 4°C: 60 days	Storage at temperature 25°C: 30 days	Storage at temperature 25°C: 60 days
1	140 (0)	300 (+1)	16000 (0)	60 (−1)	0.29 ± 0.05^{d}	0.35 ± 0.06^{cd}	0.45 ± 0.07^{bc}	0.46 ± 0.07^{bc}	0.71 ± 0.08^{ab}
2	140 (0)	250 (0)	12000 (−1)	60 (−1)	0.28 ± 0.04^{d}	0.34 ± 0.05^{cd}	0.44 ± 0.06^{bc}	0.45 ± 0.06^{bc}	0.70 ± 0.07^{ab}
3	140 (0)	200 (−1)	16000 (0)	80 (+1)	0.29 ± 0.05^{d}	0.35 ± 0.06^{cd}	0.45 ± 0.06^{bc}	0.46 ± 0.07^{bc}	0.71 ± 0.08^{ab}
4	120 (−1)	200 (−1)	16000 (0)	70 (0)	0.27 ± 0.02^{d}	0.33 ± 0.03^{cd}	0.43 ± 0.04^{bc}	0.44 ± 0.05^{bc}	0.69 ± 0.06^{ab}
5	160 (+1)	300 (+1)	16000 (0)	70 (0)	0.31 ± 0.06^{cd}	0.37 ± 0.07^{c}	0.47 ± 0.07^{bc}	0.48 ± 0.08^{b}	0.73 ± 0.09^{a}
6 (C_1)	140 (0)	250 (0)	16000 (0)	70 (0)	0.28 ± 0.04^{d}	0.35 ± 0.05^{cd}	0.45 ± 0.06^{bc}	0.46 ± 0.06^{bc}	0.71 ± 0.07^{ab}
7	120 (−1)	250 (0)	16000 (0)	80 (+1)	0.29 ± 0.04^{d}	0.36 ± 0.05^{c}	0.46 ± 0.05^{bc}	0.47 ± 0.06^{bc}	0.72 ± 0.08^{a}
8 (C_2)	140 (0)	250 (0)	16000 (0)	70 (0)	0.28 ± 0.05^{d}	0.35 ± 0.06^{cd}	0.45 ± 0.07^{bc}	0.46 ± 0.07^{bc}	0.71 ± 0.08^{ab}
9	140 (0)	200 (−1)	16000 (0)	60 (−1)	0.28 ± 0.04^{d}	0.34 ± 0.05^{cd}	0.44 ± 0.05^{bc}	0.46 ± 0.06^{bc}	0.72 ± 0.07^{a}
10	160 (+1)	250 (0)	16000 (0)	60 (−1)	0.30 ± 0.06^{d}	0.37 ± 0.07^{c}	0.47 ± 0.07^{bc}	0.48 ± 0.08^{b}	0.74 ± 0.09^{a}
11	160 (+1)	250 (0)	12000 (−1)	70 (0)	0.31 ± 0.06^{cd}	0.38 ± 0.07^{c}	0.48 ± 0.08^{b}	0.50 ± 0.08^{b}	0.75 ± 0.09^{a}
12	120 (−1)	250 (0)	12000 (−1)	70 (0)	0.27 ± 0.02^{d}	0.33 ± 0.03^{cd}	0.43 ± 0.04^{bc}	0.44 ± 0.04^{bc}	0.69 ± 0.05^{ab}
13	140 (0)	200 (−1)	20000 (−1)	70 (0)	0.28 ± 0.03^{d}	0.34 ± 0.04^{cd}	0.44 ± 0.05^{bc}	0.45 ± 0.05^{bc}	0.70 ± 0.06^{ab}
14	120 (−1)	250 (0)	16000 (0)	60 (−1)	0.26 ± 0.01^{d}	0.32 ± 0.03^{cd}	0.42 ± 0.04^{bc}	0.43 ± 0.05^{bc}	0.68 ± 0.06^{ab}
15 (C_3)	140 (0)	250 (0)	16000 (0)	70 (0)	0.28 ± 0.04^{d}	0.35 ± 0.06^{cd}	0.45 ± 0.06^{bc}	0.46 ± 0.07^{bc}	0.72 ± 0.08^{a}
16	120 (−1)	300 (+1)	16000 (0)	70 (0)	0.27 ± 0.02^{d}	0.33 ± 0.03^{cd}	0.43 ± 0.04^{bc}	0.44 ± 0.05^{bc}	0.69 ± 0.06^{ab}
17	140 (0)	250 (0)	12000 (−1)	80 (+1)	0.29 ± 0.05^{d}	0.36 ± 0.06^{c}	0.46 ± 0.07^{bc}	0.47 ± 0.08^{bc}	0.72 ± 0.09^{a}
18 (C_4)	140 (0)	250 (0)	16000 (0)	70 (0)	0.28 ± 0.04^{d}	0.35 ± 0.04^{cd}	0.45 ± 0.05^{bc}	0.46 ± 0.06^{bc}	0.71 ± 0.07^{ab}
19	140 (0)	300 (+1)	16000 (0)	80 (+1)	0.29 ± 0.05^{d}	0.36 ± 0.06^{c}	0.46 ± 0.06^{bc}	0.47 ± 0.07^{bc}	0.72 ± 0.07^{a}
20	160 (+1)	250 (0)	16000 (0)	80 (+1)	0.31 ± 0.07^{cd}	0.38 ± 0.07^{c}	0.48 ± 0.08^{b}	0.49 ± 0.08^{b}	0.75 ± 0.09^{a}
21	140 (0)	300 (+1)	12000 (−1)	70 (0)	0.28 ± 0.05^{d}	0.35 ± 0.05^{cd}	0.45 ± 0.06^{bc}	0.46 ± 0.06^{bc}	0.72 ± 0.07^{a}
22	120 (−1)	250 (0)	20000 (+1)	70 (0)	0.27 ± 0.02^{d}	0.34 ± 0.03^{cd}	0.44 ± 0.03^{bc}	0.45 ± 0.04^{bc}	0.70 ± 0.05^{ab}
23	140 (0)	250 (0)	20000 (+1)	80 (+1)	0.29 ± 0.05^{d}	0.36 ± 0.06^{c}	0.46 ± 0.06^{bc}	0.47 ± 0.07^{bc}	0.72 ± 0.07^{a}
24	140 (0)	300 (+1)	20000 (+1)	70 (0)	0.27 ± 0.03^{d}	0.34 ± 0.03^{cd}	0.45 ± 0.04^{bc}	0.46 ± 0.04^{bc}	0.72 ± 0.05^{a}
25	140 (0)	250 (0)	20000 (+1)	60 (−1)	0.27 ± 0.02^{d}	0.33 ± 0.03^{cd}	0.44 ± 0.04^{bc}	0.45 ± 0.04^{bc}	0.71 ± 0.05^{ab}
26	160 (+1)	250 (0)	20000 (+1)	70 (0)	0.31 ± 0.06^{cd}	0.38 ± 0.07^{c}	0.49 ± 0.07^{b}	0.51 ± 0.08^{b}	0.77 ± 0.09^{a}
27	160 (+1)	200 (−1)	16000 (0)	70 (0)	0.31 ± 0.06^{cd}	0.38 ± 0.06^{c}	0.48 ± 0.07^{b}	0.49 ± 0.07^{b}	0.75 ± 0.08^{a}
28	140 (0)	200 (−1)	12000 (−1)	70 (0)	0.29 ± 0.05^{d}	0.36 ± 0.06^{c}	0.45 ± 0.06^{bc}	0.45 ± 0.07^{bc}	0.70 ± 0.07^{ab}
29 (C_5)	140 (0)	250 (0)	16000 (0)	70 (0)	0.28 ± 0.04^{d}	0.35 ± 0.05^{cd}	0.45 ± 0.06^{bc}	0.46 ± 0.06^{bc}	0.72 ± 0.07^{a}
30 (C_6)	140 (0)	250 (0)	16000 (0)	70 (0)	0.28 ± 0.05^{d}	0.35 ± 0.06^{cd}	0.45 ± 0.07^{bc}	0.46 ± 0.07^{bc}	0.72 ± 0.08^{a}

^{C1,C2,C3,C4,C5,C6}Spray-drying process at center points. Experimental model = Box–Behnken design. Total number of spray-drying treatments = 30. Number of replicates = 03. $^{a\text{-}d}$Values with similar letters show homogenous groups within the row and column ($p > 0.05$).

Table 4: Impact of spray-drying conditions on peroxide value in the flaxseed oil dried powder at different days and storage intervals.

Spray-dryer process run	Independent variables				Peroxide value (meq/kg O_2)				
	Inlet air temperature (°C)	Feed flow rate (mL/hr)	Atomization speed (rpm)	Outlet temperature (°C)	0 days	Storage at temperature 4°C		Storage at temperature 25°C	
						30 days	60 days	30 days	60 days
1	140 (0)	300 (+1)	16000 (0)	60 (−1)	0.17 ± 0.0^{d}	0.22 ± 0.04^{cd}	0.29 ± 0.06^{bc}	0.35 ± 0.07^{b}	0.58 ± 0.08^{ab}
2	140 (0)	250 (0)	12000 (−1)	60 (−1)	0.16 ± 0.0^{d}	0.22 ± 0.04^{cd}	0.29 ± 0.06^{bc}	0.36 ± 0.08^{b}	0.59 ± 0.08^{a}
3	140 (0)	200 (−1)	16000 (0)	80 (+1)	0.18 ± 0.04^{cd}	0.23 ± 0.05^{c}	0.30 ± 0.07^{bc}	0.36 ± 0.08^{b}	0.60 ± 0.09^{a}
4	120 (−1)	200 (−1)	16000 (0)	70 (0)	0.16 ± 0.02^{d}	0.21 ± 0.03^{cd}	0.28 ± 0.04^{bc}	0.34 ± 0.05^{b}	0.57 ± 0.06^{ab}
5	160 (+1)	300 (+1)	16000 (0)	70 (0)	0.19 ± 0.04^{cd}	0.24 ± 0.06^{c}	0.31 ± 0.06^{bc}	0.37 ± 0.07^{b}	0.62 ± 0.07^{a}
6 (C_1)	140 (0)	250 (0)	16000 (0)	70 (0)	0.18 ± 0.03^{cd}	0.23 ± 0.04^{c}	0.30 ± 0.05^{bc}	0.35 ± 0.05^{b}	0.58 ± 0.06^{ab}
7	120 (−1)	250 (0)	16000 (0)	80 (+1)	0.16 ± 0.02^{d}	0.21 ± 0.03^{cd}	0.28 ± 0.04^{bc}	0.34 ± 0.05^{b}	0.57 ± 0.05^{ab}
8 (C_2)	140 (0)	250 (0)	16000 (0)	70 (0)	0.18 ± 0.05^{cd}	0.24 ± 0.07^{c}	0.30 ± 0.07^{bc}	0.35 ± 0.08^{b}	0.58 ± 0.08^{ab}
9	140 (0)	200 (−1)	16000 (0)	60 (−1)	0.18 ± 0.03^{cd}	0.23 ± 0.04^{c}	0.30 ± 0.05^{bc}	0.35 ± 0.06^{b}	0.58 ± 0.07^{ab}
10	160 (+1)	250 (0)	16000 (0)	60 (−1)	0.20 ± 0.05^{cd}	0.25 ± 0.06^{c}	0.31 ± 0.07^{bc}	0.37 ± 0.08^{b}	0.62 ± 0.09^{a}
11	160 (+1)	250 (0)	12000 (−1)	70 (0)	0.18 ± 0.03^{cd}	0.23 ± 0.04^{c}	0.30 ± 0.05^{bc}	0.36 ± 0.05^{b}	0.59 ± 0.06^{a}
12	120 (−1)	250 (0)	12000 (−1)	70 (0)	0.16 ± 0.02^{d}	0.21 ± 0.03^{cd}	0.28 ± 0.04^{bc}	0.34 ± 0.05^{b}	0.57 ± 0.05^{ab}
13	140 (0)	200 (−1)	20000 (−1)	70 (0)	0.17 ± 0.04^{d}	0.23 ± 0.04^{c}	0.29 ± 0.05^{bc}	0.35 ± 0.05^{b}	0.58 ± 0.06^{ab}
14	120 (−1)	250 (0)	16000 (0)	60 (−1)	0.16 ± 0.03^{d}	0.21 ± 0.04^{cd}	0.28 ± 0.05^{bc}	0.34 ± 0.06^{b}	0.57 ± 0.07^{ab}
15 (C_3)	140 (0)	250 (0)	16000 (0)	70 (0)	0.18 ± 0.04^{cd}	0.24 ± 0.05^{c}	0.30 ± 0.06^{bc}	0.35 ± 0.06^{b}	0.58 ± 0.07^{ab}
16	120 (−1)	300 (+1)	16000 (0)	70 (0)	0.16 ± 0.03^{d}	0.21 ± 0.04^{cd}	0.28 ± 0.04^{bc}	0.36 ± 0.05^{b}	0.60 ± 0.06^{a}
17	140 (0)	250 (0)	12000 (−1)	80 (+1)	0.17 ± 0.04^{d}	0.22 ± 0.05^{cd}	0.29 ± 0.06^{bc}	0.34 ± 0.06^{b}	0.57 ± 0.07^{ab}
18 (C_4)	140 (0)	250 (0)	16000 (0)	70 (0)	0.18 ± 0.04^{cd}	0.24 ± 0.05^{c}	0.30 ± 0.06^{bc}	0.35 ± 0.07^{b}	0.58 ± 0.07^{ab}
19	140 (0)	300 (+1)	16000 (0)	80 (+1)	0.18 ± 0.04^{cd}	0.23 ± 0.05^{c}	0.29 ± 0.06^{bc}	0.35 ± 0.07^{b}	0.58 ± 0.08^{ab}
20	160 (+1)	250 (0)	16000 (0)	80 (+1)	0.19 ± 0.05^{cd}	0.24 ± 0.06^{c}	0.30 ± 0.07^{bc}	0.36 ± 0.08^{b}	0.59 ± 0.09^{a}
21	140 (0)	300 (+1)	12000 (−1)	70 (0)	0.18 ± 0.04^{cd}	0.23 ± 0.05^{c}	0.30 ± 0.06^{bc}	0.35 ± 0.06^{b}	0.58 ± 0.07^{ab}
22	120 (−1)	250 (0)	20000 (+1)	70 (0)	0.16 ± 0.03^{d}	0.21 ± 0.04^{cd}	0.28 ± 0.05^{bc}	0.34 ± 0.06^{b}	0.57 ± 0.07^{ab}
23	140 (0)	250 (0)	20000 (+1)	80 (+1)	0.17 ± 0.04^{d}	0.22 ± 0.05^{cd}	0.29 ± 0.06^{bc}	0.35 ± 0.07^{b}	0.58 ± 0.08^{ab}
24	140 (0)	300 (+1)	20000 (+1)	70 (0)	0.18 ± 0.04^{cd}	0.23 ± 0.05^{c}	0.30 ± 0.06^{bc}	0.36 ± 0.07^{b}	0.59 ± 0.09^{a}
25	140 (0)	250 (0)	20000 (+1)	60 (−1)	0.17 ± 0.04^{d}	0.22 ± 0.05^{cd}	0.29 ± 0.05^{bc}	0.35 ± 0.06^{b}	0.58 ± 0.07^{ab}
26	160 (+1)	250 (0)	20000 (+1)	70 (0)	0.19 ± 0.05^{cd}	0.24 ± 0.06^{c}	0.31 ± 0.07^{bc}	0.36 ± 0.08^{b}	0.58 ± 0.09^{ab}
27	160 (+1)	200 (−1)	16000 (0)	70 (0)	0.19 ± 0.05^{cd}	0.24 ± 0.06^{c}	0.30 ± 0.07^{bc}	0.36 ± 0.08^{b}	0.59 ± 0.09^{a}
28	140 (0)	200 (−1)	12000 (−1)	70 (0)	0.17 ± 0.04^{d}	0.23 ± 0.05^{c}	0.29 ± 0.06^{bc}	0.35 ± 0.06^{b}	0.58 ± 0.07^{ab}
29 (C_5)	140 (0)	250 (0)	16000 (0)	70 (0)	0.18 ± 0.04^{cd}	0.24 ± 004^{c}	0.30 ± 0.05^{bc}	0.35 ± 0.06^{b}	0.58 ± 0.07^{ab}
30 (C_6)	140 (0)	250 (0)	16000 (0)	70 (0)	0.18 ± 0.05^{cd}	0.24 ± 0.05^{c}	0.30 ± 0.06^{bc}	0.35 ± 0.07^{b}	0.58 ± 0.08^{ab}

^{C1,C2,C3,C4,C5,C6}Spray-drying process at center points. Experimental model = Box–Behnken design. Total number of spray-drying treatments = 30. Number of replicates = 03. $^{a\text{-}d}$Values with similar letters show homogenous groups within the row and column ($p > 0.05$).

Table 5: Impact of spray-drying conditions on malondialdehyde in the flaxseed oil dried powder at different days and storage intervals.

Spray-dryer process run	Independent variables: Inlet air temperature (°C)	Feed flow rate (mL/hr)	Atomization speed (rpm)	Outlet temperature (°C)	Malondialdehyde (nmol/g of lipids): 0 days	Storage at temperature 4°C: 30 days	Storage at temperature 4°C: 60 days	Storage at temperature 25°C: 30 days	Storage at temperature 25°C: 60 days
1	140 (0)	300 (+1)	16000 (0)	60 (−1)	0.20 ± 0.04^{bc}	0.24 ± 0.05^{bc}	0.30 ± 0.05^{ab}	0.31 ± 0.06^{ab}	0.45 ± 0.07^{a}
2	140 (0)	250 (0)	12000 (−1)	60 (−1)	0.20 ± 0.03^{bc}	0.24 ± 0.04^{bc}	0.29 ± 0.05^{b}	0.30 ± 0.05^{ab}	0.44 ± 0.06^{a}
3	140 (0)	200 (−1)	16000 (0)	80 (+1)	0.22 ± 0.05^{bc}	0.26 ± 0.05^{b}	0.32 ± 0.06^{ab}	0.33 ± 0.07^{ab}	0.47 ± 0.08^{a}
4	120 (−1)	200 (−1)	16000 (0)	70 (0)	0.18 ± 0.02^{c}	0.22 ± 0.03^{bc}	0.28 ± 0.04^{b}	0.29 ± 0.05^{b}	0.43 ± 0.05^{a}
5	160 (+1)	300 (+1)	16000 (0)	70 (0)	0.22 ± 0.05^{bc}	0.26 ± 0.06^{b}	0.32 ± 0.06^{ab}	0.33 ± 0.07^{ab}	0.47 ± 0.08^{a}
6 (C_1)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.04^{bc}	0.25 ± 0.05^{b}	0.31 ± 0.06^{ab}	0.32 ± 0.06^{ab}	0.46 ± 0.07^{a}
7	120 (−1)	250 (0)	16000 (0)	80 (+1)	0.19 ± 0.03^{c}	0.24 ± 0.04^{bc}	0.30 ± 0.04^{ab}	0.30 ± 0.06^{ab}	0.44 ± 0.07^{a}
8 (C_2)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.05^{bc}	0.25 ± 0.05^{b}	0.31 ± 0.06^{ab}	0.32 ± 0.07^{ab}	0.46 ± 0.08^{a}
9	140 (0)	200 (−1)	16000 (0)	60 (−1)	0.20 ± 0.04^{bc}	0.24 ± 0.05^{bc}	0.30 ± 0.05^{ab}	0.32 ± 0.06^{ab}	0.45 ± 0.07^{a}
10	160 (+1)	250 (0)	16000 (0)	60 (−1)	0.23 ± 0.05^{bc}	0.27 ± 0.06^{b}	0.31 ± 0.07^{ab}	0.32 ± 0.08^{ab}	0.47 ± 0.09^{a}
11	160 (+1)	250 (0)	12000 (−1)	70 (0)	0.24 ± 0.06^{bc}	0.28 ± 0.07^{b}	0.32 ± 0.07^{ab}	0.33 ± 0.08^{ab}	0.47 ± 0.09^{a}
12	120 (−1)	250 (0)	12000 (−1)	70 (0)	0.18 ± 0.02^{c}	0.22 ± 0.03^{bc}	0.28 ± 0.04^{b}	0.29 ± 0.04^{b}	0.43 ± 0.05^{a}
13	140 (0)	200 (−1)	20000 (−1)	70 (0)	0.20 ± 0.04^{bc}	0.24 ± 0.05^{bc}	0.30 ± 0.05^{ab}	0.31 ± 0.07^{ab}	0.45 ± 0.07^{a}
14	120 (−1)	250 (0)	16000 (0)	60 (−1)	0.17 ± 0.01^{c}	0.22 ± 0.02^{bc}	0.28 ± 0.03^{b}	0.29 ± 0.03^{b}	0.43 ± 0.04^{a}
15 (C_3)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.04^{bc}	0.25 ± 0.05^{b}	0.31 ± 0.06^{ab}	0.32 ± 0.07^{ab}	0.46 ± 0.08^{a}
16	120 (−1)	300 (+1)	16000 (0)	70 (0)	0.18 ± 0.02	0.22 ± 0.03^{bc}	0.28 ± 0.04^{b}	0.30 ± 0.05^{ab}	0.44 ± 0.06^{a}
17	140 (0)	250 (0)	12000 (−1)	80 (+1)	0.22 ± 0.05^{bc}	0.26 ± 0.05^{b}	0.28 ± 0.06^{b}	0.29 ± 0.07^{b}	0.43 ± 0.08^{a}
18 (C_4)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.03^{bc}	0.25 ± 0.04^{b}	0.31 ± 0.04^{ab}	0.32 ± 0.05^{ab}	0.47 ± 0.06^{a}
19	140 (0)	300 (+1)	16000 (0)	80 (+1)	0.22 ± 0.04^{bc}	0.26 ± 0.05^{b}	0.32 ± 0.05^{ab}	0.33 ± 0.06^{ab}	0.47 ± 0.07^{a}
20	160 (+1)	250 (0)	16000 (0)	80 (+1)	0.24 ± 0.06^{bc}	0.28 ± 0.07^{b}	0.34 ± 0.07^{ab}	0.34 ± 0.08^{ab}	0.48 ± 0.08^{a}
21	140 (0)	300 (+1)	12000 (−1)	70 (0)	0.21 ± 0.05^{bc}	0.25 ± 0.06^{b}	0.31 ± 0.07^{ab}	0.32 ± 0.07^{ab}	0.47 ± 0.07^{a}
22	120 (−1)	250 (0)	20000 (+1)	70 (0)	0.18 ± 0.02	0.22 ± 0.03^{bc}	0.28 ± 0.04^{b}	0.29 ± 0.05^{b}	0.43 ± 0.06^{a}
23	140 (0)	250 (0)	20000 (+1)	80 (+1)	0.22 ± 0.05^{bc}	0.26 ± 0.06^{b}	0.32 ± 0.06^{ab}	0.33 ± 0.07^{ab}	0.47 ± 0.07^{a}
24	140 (0)	300 (+1)	20000 (+1)	70 (0)	0.21 ± 0.03^{bc}	0.25 ± 0.04^{b}	0.31 ± 0.05^{ab}	0.32 ± 0.05^{ab}	0.46 ± 0.06^{a}
25	140 (0)	250 (0)	20000 (+1)	60 (−1)	0.20 ± 0.04^{bc}	0.24 ± 0.04^{c}	0.30 ± 0.05^{ab}	0.31 ± 0.06^{ab}	0.46 ± 0.06^{a}
26	160 (+1)	250 (0)	20000 (+1)	70 (0)	0.23 ± 0.05^{bc}	0.27 ± 0.06^{b}	0.33 ± 0.06^{ab}	0.33 ± 0.07^{ab}	0.47 ± 0.08^{a}
27	160 (+1)	200 (−1)	16000 (0)	70 (0)	0.23 ± 0.04^{bc}	0.27 ± 0.05^{b}	0.33 ± 0.05^{ab}	0.34 ± 0.06^{ab}	0.48 ± 0.07^{a}
28	140 (0)	200 (−1)	12000 (−1)	70 (0)	0.20 ± 0.03^{bc}	0.24 ± 0.04^{bc}	0.30 ± 0.05^{ab}	0.31 ± 0.05^{ab}	0.45 ± 0.06^{a}
29 (C_5)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.06^{bc}	0.25 ± 0.06^{b}	0.31 ± 0.07^{ab}	0.32 ± 0.08^{ab}	0.46 ± 0.09^{a}
30 (C_6)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.05^{bc}	0.25 ± 0.06^{b}	0.31 ± 0.07^{ab}	0.32 ± 0.08^{ab}	0.46 ± 0.08^{a}

[C1,C2,C3,C4,C5,C6]Spray-drying process at center points. Experimental model = Box–Behnken design. Total number of spray-drying treatments = 30. Number of replicates = 03. [a-c]Values with similar letters show homogenous groups within the row and column ($p > 0.05$).

Table 6: Impact of spray-drying conditions on conjugated dienes in flaxseed oil dried powder at different days and storage intervals.

Spray-dryer process run	Independent variables				Conjugated dienes				
	Inlet air temperature (°C)	Feed flow rate (mL/hr)	Atomization speed (rpm)	Outlet temperature (°C)	0 days	Storage at temperature 4°C		Storage at temperature 25°C	
						30 days	60 days	30 days	60 days
1	140 (0)	300 (+1)	16000 (0)	60 (−1)	0.20 ± 0.04^{ef}	0.21 ± 0.05^{e}	0.23 ± 0.06^{d}	0.24 ± 0.07^{cd}	0.26 ± 0.07^{bc}
2	140 (0)	250 (0)	12000 (−1)	60 (−1)	0.20 ± 0.03^{ef}	0.21 ± 0.04^{e}	0.23 ± 0.05^{d}	0.24 ± 0.05^{cd}	0.26 ± 0.06^{bc}
3	140 (0)	200 (−1)	16000 (0)	80 (+1)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.24 ± 0.06^{cd}	0.25 ± 0.06^{c}	0.27 ± 0.07^{b}
4	120 (−1)	200 (−1)	16000 (0)	70 (0)	0.19 ± 0.02^{f}	0.21 ± 0.03^{e}	0.22 ± 0.04^{de}	0.23 ± 0.05^{d}	0.25 ± 0.05^{c}
5	160 (+1)	300 (+1)	16000 (0)	70 (0)	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.26 ± 0.07^{bc}	0.26 ± 0.08^{bc}	0.27 ± 0.08^{b}
6 (C_1)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.27 ± 0.08^{b}
7	120 (−1)	250 (0)	16000 (0)	80 (+1)	0.20 ± 0.03^{ef}	0.21 ± 0.04^{e}	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.26 ± 0.07^{bc}
8 (C_2)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.05^{e}	0.22 ± 0.06^{de}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.27 ± 0.08^{b}
9	140 (0)	200 (−1)	16000 (0)	60 (−1)	0.20 ± 0.03^{ef}	0.21 ± 0.03^{e}	0.23 ± 0.04^{d}	0.24 ± 0.05^{cd}	0.26 ± 0.06^{bc}
10	160 (+1)	250 (0)	16000 (0)	60 (−1)	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.26 ± 0.07^{bc}	0.27 ± 0.08^{b}	0.28 ± 0.09^{ab}
11	160 (+1)	250 (0)	12000 (−1)	70 (0)	0.22 ± 0.04^{de}	0.23 ± 0.05^{d}	0.25 ± 0.06^{c}	0.25 ± 0.07^{c}	0.26 ± 0.08^{bc}
12	120 (−1)	250 (0)	12000 (−1)	70 (0)	0.19 ± 0.02^{f}	0.20 ± 0.04^{ef}	0.22 ± 0.05^{de}	0.23 ± 0.06^{d}	0.25 ± 0.07^{c}
13	140 (0)	200 (−1)	20000 (−1)	70 (0)	0.21 ± 0.04^{e}	0.23 ± 0.05^{d}	0.25 ± 0.05^{c}	0.25 ± 0.06^{c}	0.27 ± 0.06^{b}
14	120 (−1)	250 (0)	16000 (0)	60 (−1)	0.18 ± 0.01^{fg}	0.20 ± 0.02^{ef}	0.22 ± 0.03^{de}	0.23 ± 0.04^{d}	0.25 ± 0.05^{c}
15 (C_3)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.24 ± 0.05^{cd}	0.25 ± 0.06^{c}	0.27 ± 0.07^{b}
16	120 (−1)	300 (+1)	16000 (0)	70 (0)	0.19 ± 0.02^{f}	0.20 ± 0.03^{ef}	0.23 ± 0.03^{d}	0.24 ± 0.04^{cd}	0.25 ± 0.05^{c}
17	140 (0)	250 (0)	12000 (−1)	80 (+1)	0.22 ± 0.04^{de}	0.24 ± 0.05^{cd}	0.26 ± 0.07^{bc}	0.27 ± 0.07^{b}	0.29 ± 0.08^{a}
18 (C_4)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.27 ± 0.08^{b}
19	140 (0)	300 (+1)	16000 (0)	80 (+1)	0.22 ± 0.05^{de}	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.27 ± 0.08^{b}
20	160 (+1)	250 (0)	16000 (0)	80 (+1)	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.26 ± 0.06^{bc}	0.27 ± 0.07^{b}	0.29 ± 0.09^{a}
21	140 (0)	300 (+1)	12000 (−1)	70 (0)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.23 ± 0.06^{d}	0.24 ± 0.07^{cd}	0.26 ± 0.07^{bc}
22	120 (−1)	250 (0)	20000 (+1)	70 (0)	0.20 ± 0.03^{ef}	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.23 ± 0.06^{d}	0.25 ± 0.06^{c}
23	140 (0)	250 (0)	20000 (+1)	80 (+1)	0.22 ± 0.04^{de}	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.27 ± 0.08^{b}
24	140 (0)	300 (+1)	20000 (+1)	70 (0)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.26 ± 0.08^{bc}
25	140 (0)	250 (0)	20000 (+1)	60 (−1)	0.20 ± 0.02^{ef}	0.21 ± 0.87^{e}	0.22 ± 0.81^{de}	0.23 ± 0.77^{d}	0.25 ± 0.68^{c}
26	160 (+1)	250 (0)	20000 (+1)	70 (0)	0.23 ± 0.05^{d}	0.24 ± 0.06^{cd}	0.26 ± 0.06^{bc}	0.26 ± 0.07^{bc}	0.27 ± 0.08^{b}
27	160 (+1)	200 (−1)	16000 (0)	70 (0)	0.23 ± 0.05^{d}	0.24 ± 0.05^{cd}	0.26 ± 0.06^{bc}	0.27 ± 0.07^{b}	0.28 ± 0.08^{ab}
28	140 (0)	200 (−1)	12000 (−1)	70 (0)	0.22 ± 0.04^{de}	0.23 ± 0.05^{d}	0.25 ± 0.06^{c}	0.26 ± 0.07^{bc}	0.28 ± 0.09^{ab}
29 (C_5)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.03^{e}	0.23 ± 0.04^{d}	0.25 ± 0.05^{c}	0.25 ± 0.06^{c}	0.27 ± 0.07^{b}
30 (C_6)	140 (0)	250 (0)	16000 (0)	70 (0)	0.21 ± 0.04^{e}	0.22 ± 0.05^{de}	0.24 ± 0.06^{cd}	0.25 ± 0.07^{c}	0.27 ± 0.08^{b}

^{C1,C2,C3,C4,C5,C6}Spray-drying process at center points. Experimental model = Box–Behnken design. Total number of spray-drying treatments = 30. Number of replicates = 03. $^{a\text{-}fg}$Values with similar letters show homogenous groups within the row and column ($p > 0.05$).

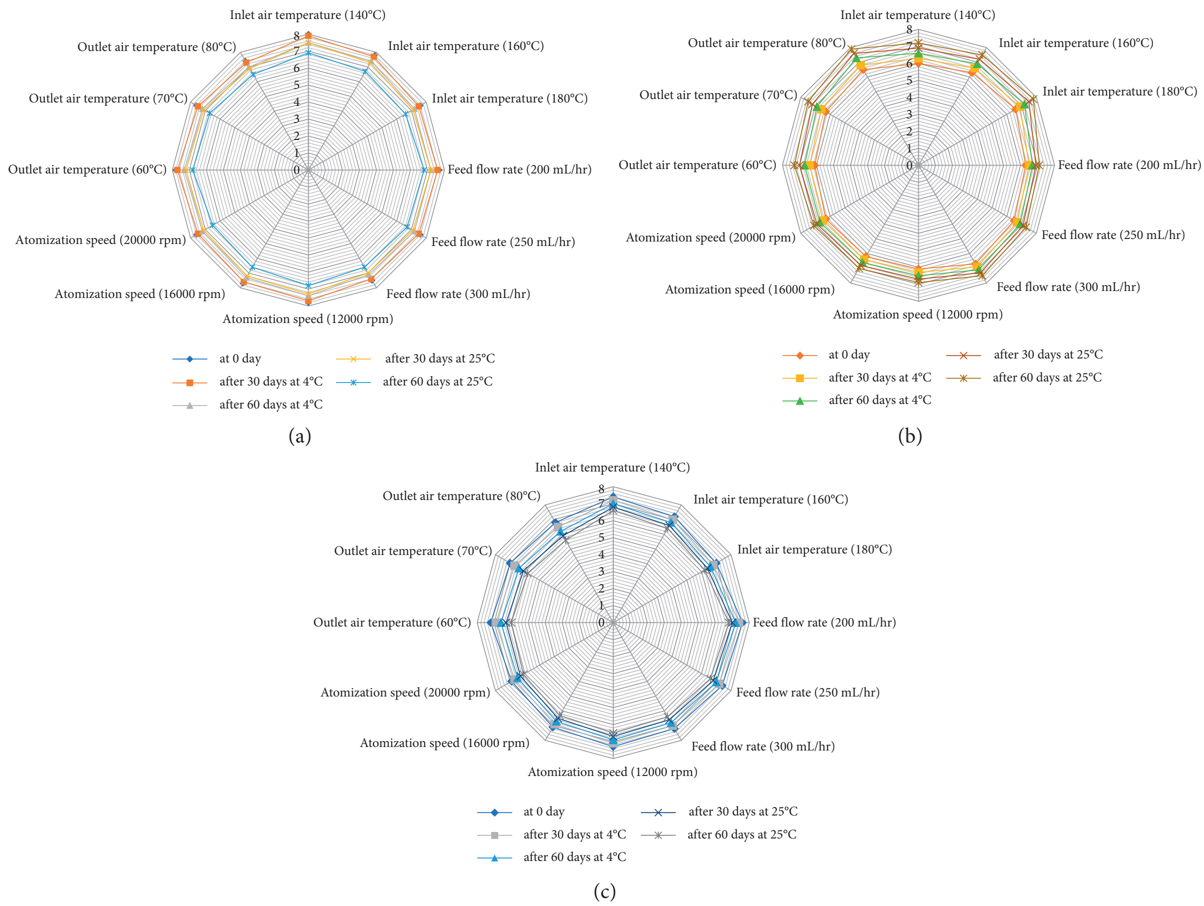

Figure 4: Sensoric evaluation of spray-dried flaxseed oil samples at different temperatures and storage intervals. (a) Color score. (b) Off-flavor score. (c) Overall acceptability score.

The data pertaining to MDA concentration of SDFSO powder stored at temperatures 4°C and 25°C for a period of 0, 30, and 60 days are presented in Table 5. The value for MDA of FSO samples was increased from 0.16 ± 0.02 nmol/g of lipids (0 day) to 0.39 ± 0.06 nmol/g of lipids at 60 days (4°C) while the value for MDA of SDFSO samples was increased from 0.17 ± 0.01 nmol/g of lipids (0 day) to 0.34 ± 0.07 nmol/g of lipids at 60 days (4°C), and the same increasing trend was observed at 25°C. It has been observed in different previous research studies that the reaction of free oxygen with unsaturated oils (lipid peroxidation) generates a wide variety of oxidation products. From many years, MDA has been extensively used as an expedient biomarker for lipid peroxidation of PUFAs due to its reaction with thiobarbituric acid (TBA). It is actually a product generated by decomposition of arachidonic and large chain PUFAs. MDA reacts with cellular and tissue proteins or DNA to form products resultantly, causing biomolecular damages leading to disease [34].

The results for effects of various storage time intervals for CDs are shown in Table 6. The maximum value for control samples was observed 0.32 ± 0.08 while the maximum value was recorded as 0.29 ± 0.09 under four factors of a spray-dryer, i.e., inlet air temperature (160°C), outlet air temperature (80°C), feed flow rate (300 mL/hr), and atomization speed (20000 rpm) for the SDFSO samples stored at 25°C after 60 days of storage. The results of the current study can be explained by the fact that the CDs decompose into secondary volatile oxidation products by high temperature at the commencement of the microencapsulation process. The data indicate that the level of CDs in the SDFSO samples showed a nonsignificantly increasing trend until the second month of storage. However, none of the value went beyond its safe limit. These observations are in harmony with previous results recorded by Kolanowski et al. [35] as they narrated that the encapsulated fish oil oxidized quickly in the presence of air. Nevertheless, stability was enhanced when the powder was stored under vacuum. Similar results were also reported by Drusch et al. [36], who noticed incline in level of CDs in microencapsulated fish oil kept in closed bottles and stored for 17 days at 20°C. Reduction in stability of microencapsulated oil samples stored in contact with oxygen might be due to increased ratio of surface-to-oil volume and subsequently higher accessibility of oxygen to these oils [37].

3.5. Sensoric Evaluation of the SDFSO Samples. The FSO (control) and SDFSO samples were also evaluated for different sensory parameters like color, off-flavors, and overall acceptability as depicted in Figure 4. The data regarding scores of different attributes highlight the differences due to spray-drying and storage condition as well as storage duration. The average hedonic scores assigned to color, off-flavor, and overall acceptability differ in a quite narrow range for all SDFSO samples at the start of the storage period, irrespective of the encapsulation processing conditions. In the case of color and overall acceptability, the lowest evaluation scores were awarded to the FSO samples. Furthermore, the highest score for off-flavor was attributed to FSO samples stored at high temperature for 60 days of storage.

4. Conclusions

The results of the present study conclude that the optimized SDFSO powder showed maximum encapsulation efficiency and retention of omega-3 fatty acids as compared to FSO control samples. The validated optimized inlet air temperature (120°C), feed flow rate (250 mL/hr), atomization speed (16000 rpm), and outlet air temperature (60°C) conditions were found for maximum retention of ALA, oxidative stability, and sensoric acceptability. The results further revealed that SDFSO samples were oxidatively stable and the process of spray-drying did not significantly alter the sensoric attributes during different storage intervals. Furthermore, the present study suggests that the incorporation of SDFSO powder into different food products and their effect in the biological system should be evaluated in future studies.

Data Availability

The datasets supporting the conclusions of this article are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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