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Formulation and Evaluation of Functional Oil Blends with a Balanced Omega-6 and Omega-3 Fatty Acid Ratio for Mayonnaise Production

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Abstract This study investigated the impact of functional vegetable oil blends on the oxidative stability and quality characteristics of mayonnaise during 180-day storage. Four vegetable oils (corn, sesame, soybean, and sunflower) were analyzed for physicochemical properties, fatty acid composition, and biologically active compounds. Fourteen oil blends with varying proportions were formulated to optimize the omega-6 to omega-3 (ω-6:ω-3) fatty acid ratio while maintaining oxidative stability. Results showed that all individual oils contained 83.2%–88.7% unsaturated fatty acids, with only soybean oil achieving the recommended ω-6:ω-3 ratio of 6.4:1. Corn oil exhibited the highest phytosterol content (870.9 mg/100 g), while sesame oil was the exclusive source of lignans (514.2 mg/100 g). Mayonnaise samples prepared with oil blends were evaluated for peroxide and anisidine values throughout storage. The optimal blend composition of 60:30:10 (soybean:sesame:corn) achieved a ω-6:ω-3 ratio of approximately 10:1 with acceptable oxidative stability (peroxide value 6.8 mmol O_2/kg after 180 days). Increasing soybean oil content enhanced tocopherol levels but reduced phytosterols, squalene, and lignans, resulting in decreased oxidative stability due to higher polyunsaturated fatty acid concentration.

Keywords Mayonnaise, Functional oils, Oxidative stability, Omega-3 fatty acids, Oil blends, Phytosterols, Tocopherols

1. Introduction

Mayonnaise is one of the most widely consumed oil-in-water emulsion products globally, with vegetable oils constituting approximately 70–80% of its composition [5]. The nutritional quality and oxidative stability of mayonnaise are primarily determined by the type and composition of oils used in its formulation. Contemporary consumer demand for functional foods has driven research toward developing mayonnaise products with enhanced nutritional profiles [1,2], particularly regarding essential fatty acid balance and bioactive compound content.

The ratio of omega-6 to omega-3 (ω-6:ω-3) polyunsaturated fatty acids (PUFAs) in the human diet has received considerable attention due to its implications for cardiovascular health, inflammatory responses, and chronic disease prevention [20,21]. Current Western diets typically exhibit ω-6:ω-3 ratios ranging from 15:1 to 20:1 [20], substantially higher than the recommended ratio of 5:1 to 10:1 [21]. Vegetable oils represent a primary dietary source of these essential fatty acids, making them critical targets for nutritional optimization in processed foods.

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Beyond fatty acid composition, vegetable oils contain various biologically active compounds including tocopherols, phytosterols, carotenoids, phospholipids, squalene, and lignans [9]. These compounds contribute not only to the nutritional value of oil-based products but also serve as natural antioxidants that influence oxidative stability during processing and storage. Tocopherols function as primary chain-breaking antioxidants [10], while phytosterols have been associated with cholesterol-lowering effects [14,16]. Lignans, particularly abundant in sesame oil, exhibit antioxidant and potential anticancer properties [15].

However, a fundamental challenge exists in formulating mayonnaise with optimized fatty acid profiles: oils rich in omega-3 fatty acids and other PUFAs are inherently more susceptible to oxidative degradation [4,6]. Lipid oxidation in mayonnaise leads to the formation of hydroperoxides, aldehydes, ketones, and other secondary oxidation products [13] that compromise sensory quality, nutritional value, and safety. The peroxide value and anisidine value serve as key indicators of primary and secondary oxidation products [19], respectively.

Previous studies have explored various strategies to enhance mayonnaise stability, including the use of natural antioxidants, modified processing conditions, and alternative oil sources [1,5,13]. However, limited research has systematically investigated the relationship between functional oil blend composition, bioactive compound profiles, and long-term oxidative stability in mayonnaise systems. Understanding these relationships is essential for developing mayonnaise products that simultaneously meet nutritional recommendations and maintain acceptable shelf life without excessive reliance on synthetic additives.

The objectives of this study were to: (1) characterize the physicochemical properties, fatty acid composition, and bioactive compound content of four functional vegetable oils (corn, sesame, soybean, and sunflower); (2) develop and evaluate oil blends with optimized ω-6:ω-3 ratios; (3) assess the physicochemical properties and bioactive compound profiles of selected oil blends.

2. Materials and Methods

2.1. Materials

Four refined vegetable oils were obtained from commercial sources: corn oil, sesame oil, soybean oil, and sunflower oil. All oils met quality standards for refined edible oils according to international specifications.

2.2. Oil Blend Preparation

Fourteen oil blends were prepared by mixing soybean, sesame, corn, and sunflower oils in varying proportions to achieve target ω-6:ω-3 fatty acid ratios. Oils were weighed using an analytical balance (precision ±0.01 g) and thoroughly mixed at room temperature (20 ± 2 ℃) using a magnetic stirrer for 30 minutes to ensure homogeneity. Blend compositions ranged from equal proportions (25:25:25:25) to soybean-dominant formulations (up to 90% soybean oil). Based on preliminary fatty acid analysis and oxidative stability screening, four blends were selected for detailed characterization: 60:30:10:0, 70:20:10:0, 80:10:10:0, and 90:5:5:0 (soybean:sesame:corn:sunflower, % w/w).

2.3. Analytical Methods

Physicochemical properties: Density was determined at 20 ℃ using a pycnometer according to standard methods. Kinematic viscosity was measured at 20 ℃ using a calibrated Ubbelohde viscometer. Refractive index was determined at 20 ℃ using an Abbe refractometer. Iodine value was determined by the Wijs method. Saponification value was measured by standard alkaline hydrolysis. Acid value was determined by titration with standardized potassium hydroxide solution. Peroxide value was measured by the iodometric method and expressed as mmol O_2/kg oil. Anisidine value was determined spectrophotometrically at 350 nm.

Fatty acid composition: Fatty acid methyl esters (FAMEs) were prepared by transesterification with methanolic sodium hydroxide followed by boron trifluoride-methanol reagent. FAMEs were analyzed by gas chromatography using a capillary column (30 m × 0.25 mm i.d., 0.25 μm film thickness) with flame ionization detection. Fatty acids were identified by comparison with authentic standards and quantified as percentage of total fatty acids.

Biologically active compounds: Total tocopherol content was determined by high-performance liquid chromatography (HPLC) with fluorescence detection following saponification and extraction. Phytosterol content was measured by gas chromatography-mass spectrometry (GC-MS) after derivatization. Carotenoid content was determined spectrophotometrically at 450 nm after extraction with petroleum ether. Phospholipid content was determined by phosphorus analysis following acid digestion. Squalene content was measured by HPLC with UV detection at 210 nm. Lignan content (sesamin and sesamolin) was determined by HPLC with UV detection at 280 nm.

2.4. Statistical Analysis

All analyses were performed in triplicate, and results are expressed as mean ± standard deviation. Data were analyzed using analysis of variance (ANOVA) followed by Tukey's post-hoc test for multiple comparisons. Statistical significance was set at $p < 0.05$. Correlation analysis was performed to assess relationships between oil blend composition, bioactive compound content, and oxidative stability parameters.

3. Result and Discussion

3.1. Biologically Active Compounds in Individual Oils

The biologically active compound profiles of the four vegetable oils are presented in Table 1. Substantial differences were observed among the oils, reflecting their distinct botanical origins and processing histories.

Soybean oil exhibited the highest tocopherol content (110.8 mg/100 g), followed by corn oil (97.2 mg/100 g), sunflower oil (61.4 mg/100 g), and sesame oil (43.6 mg/100 g). The predominant tocopherol isomers varied among oils, with γ-tocopherol being most abundant in soybean and corn oils, while α-tocopherol predominated in sunflower oil [10].

Phytosterol content was highest in corn oil (870.9 mg/100 g) and sesame oil (645.7 mg/100 g), substantially exceeding the levels found in soybean oil (302.5 mg/100 g) and sunflower oil (327.8 mg/100 g). β-sitosterol, campesterol, and stigmasterol were the major phytosterols identified in all oils [14].

Carotenoid content was relatively low in all oils, with corn oil showing the highest concentration (1.2 mg/kg). Phospholipid content was uniformly low across all oils (0.02–0.03%), consistent with their refined status.

Squalene content varied considerably, with sesame oil containing the highest level [8] (25.3 mg/100 g), followed by corn oil (11.5 mg/100 g), soybean oil (5.2 mg/100 g), and sunflower oil (3.1 mg/100 g).

A distinctive finding was the exclusive presence of lignans in sesame oil [7,12,15] (514.2 mg/100 g), comprising primarily sesamin and sesamolin [7,12]. These compounds were not detected in corn, soybean, or sunflower oils, highlighting the unique phytochemical profile of sesame oil.

3.2. Oil Blend Development and Fatty Acid Ratios

The data presented in Table 2 indicate that increasing the proportion of soybean oil in the blend from 25% to 90% resulted in a decrease in the ω-3:ω-6 ratio from 23.47:1 to 7.06:1. When the soybean oil content exceeded 60%, the ω-3:ω-6 ratio fell below 10:1.

However, this was achieved only in blends that contained no sunflower oil, with sesame oil and corn oil accounting for 30% and 10% of the blend, respectively. When the proportion of soybean oil exceeded 70%, the ω-3:ω-6 ratio remained below 10:1 regardless of the proportions of the other oils in the blend.

The obtained results suggest that soybean oil constitutes the largest proportion of the blend, followed by sesame oil, corn oil, and finally sunflower oil.

An examination of blends 6–11 revealed that the absence of sunflower oil contributed to a reduction in the ω-3:ω-6 ratio. This observation suggests that sunflower oil may be excluded from the oil blend formulation. Although sunflower oil is less expensive than the other oils, its content of biologically active compounds is comparatively low. Therefore, omitting sunflower oil from the mayonnaise formulation does not hinder the achievement of the intended objectives.

In subsequent experiments, the effects of oil blend composition on the contents of ω-3 and ω-6 fatty acids and their mutual ratios were investigated. The obtained results are presented in Figure 1.

The data presented in Figure 1. indicate that increasing the proportion of soybean oil in the blend from 60% to 100% resulted in an increase in the linolenic acid content from 5.15% to 8.50%, while the ω-3:ω-6 ratio decreased from 9.98 to 6.40.

Based on the results presented in Table 2. and Figure 1., it can be concluded that the ω-3:ω-6 ratio decreases below 10:1 when the proportion of soybean oil in the blend exceeds 60%. However, when the soybean oil content is maintained at 60%, the proportion of sesame oil in the blend should not be less than 30%. At higher or lower soybean oil proportions, the remaining 40% of the blend may consist of sesame and corn oils in various ratios.

Table 1. Biologically Active Compounds in Individual Vegetable Oils

Parameters	Corn Oil	Sesame Oil	Soybean Oil	Sunflower Oil
Tocopherols (mg/100 g)	97.2	43.6	110.8	61.4
Phytosterols (mg/100 g)	870.9	645.7	302.5	327.8
Carotenoids (mg/kg)	1.2	0.3	0.6	0.3
Phospholipids (%)	0.02	0.02	0.03	0.02
Squalene (mg/100 g)	11.5	25.3	5.2	3.1
Lignans (mg/100 g)	Not detected	514.2	Not detected	Not detected

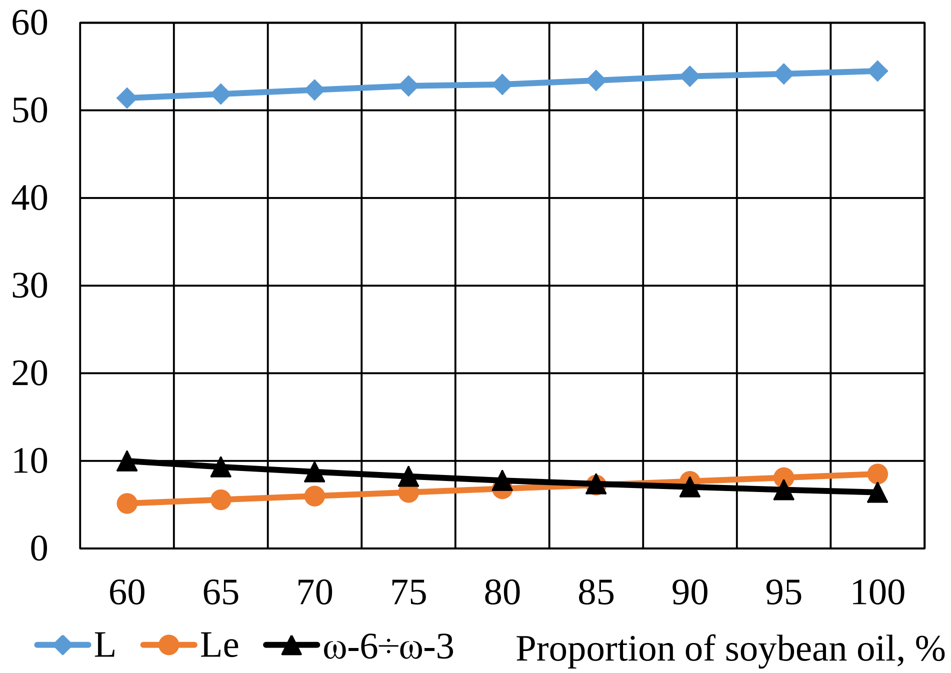

Figure 1. Changes in the Contents of ω-3 and ω-6 Fatty Acids and their Ratio as a Function of the Proportions of Oils in the Blend

Table 2. Composition and Omega-6 to Omega-3 Fatty Acid Ratios of Oil Blends

Blend №.	Soybean Oil (%)	Sesame Oil (%)	Corn Oil (%)	Sunflower Oil (%)	ω-6:ω-3 Ratio
1	25	25	25	25	23.47:1
2	50	16.7	16.7	16.6	12.27:1
3	50	20	20	10	12.12:1
4	50	10	20	20	12.41:1
5	50	20	10	20	12.30:1
6	60	20	10	10	10.23:1
7	60	10	30	0	10.17:1
8	60	30	10	0	9.98:1
9	70	10	10	10	8.95:1
10	70	20	10	0	8.74:1
11	70	10	20	0	8.82:1
12	80	10	5	5	7.85:1
13	85	5	5	5	7.46:1
14	90	4	3	3	7.06:1

3.3. Physicochemical Properties of Selected Oil Blends

The physicochemical properties of the four selected oil blends are presented in Table 3. All blends exhibited properties within acceptable ranges for refined vegetable oils.

Density decreased slightly with increasing soybean oil content [9,22], ranging from 0.9206 g/cm ^{3}(60:30:10 blend) to 0.9202 g/cm ^{3}(90:5:5 blend). Similarly, viscosity decreased from 35.23 mm ^{2}/s to 34.64 mm ^{2}/s as soybean oil proportion increased. These trends reflect the slightly lower density and viscosity of soybean oil compared to sesame and corn oils.

Refractive index remained relatively constant across all blends (1.4660–1.4662), indicating similar overall unsaturation levels. However, iodine value showed an increasing trend with higher soybean oil content [18,22], rising from 116.96 g I_2/100 g (60:30:10) to 118.98 g I_2/100 g (80:10:10), before slightly decreasing to 118.59 g I_2/100 g (90:5:5). This pattern reflects the higher content of polyunsaturated fatty acids, particularly linolenic acid, in soybean oil.

Saponification value remained essentially constant (189.41–189.52 mg KOH/g), indicating similar average molecular weights of fatty acids across blends. Acid value decreased progressively with increasing soybean oil content, from 0.826 mg KOH/g (60:30:10) to 0.465 mg KOH/g (90:5:5), suggesting that the soybean oil used had lower initial free fatty acid content than sesame and corn oils.

Peroxide value showed an increasing trend with higher soybean oil content [4,6], ranging from 6.27 mmol O_2/kg (60:30:10) to 6.73 mmol O_2/kg (90:5:5). This observation indicates greater susceptibility to oxidation in blends with higher polyunsaturated fatty acid content [4,13], even in the initial state before mayonnaise production.

3.4. Fatty Acid Composition of Oil Blends

The fatty acid composition of the four selected oil blends is presented in Table 4. Systematic changes in fatty acid profile were observed as a function of blend composition.

Palmitic acid (C16:0) content increased slightly from 9.67% to 9.76% with increasing soybean oil proportion, reflecting the moderate palmitic acid content of soybean oil. Conversely, stearic acid (C18:0) decreased from 4.93% to 4.45%, as soybean oil contains relatively less stearic acid than sesame and corn oils.

Oleic acid (C18:1), the primary monounsaturated fatty acid, decreased substantially from 28.53% to 24.10% [9,11] as soybean oil content increased. This trend reflects the lower oleic acid content of soybean oil compared to sesame and corn oils, which are richer in this monounsaturated fatty acid.

Linoleic acid (C18:2, ω-6) increased from 51.53% to 54.06% [20,21] with higher soybean oil content. More dramatically, linolenic acid (C18:3, ω-3) increased from 5.03% to 7.48% [20,21], representing a 49% relative increase. This substantial increase in omega-3 fatty acid content was the primary driver of the improved ω-6:ω-3 ratio [20] in soybean-rich blends.

The proportion of other minor fatty acids (including behenic, arachidic, and eicosenoic acids) decreased from 0.31% to 0.15% with increasing soybean oil content. Total unsaturated fatty acids (oleic + linoleic + linolenic) ranged from 85.09% to 85.65% [18] across all blends, confirming the high degree of unsaturation in all formulations.

3.5. Biologically Active Compounds in Oil Blends

The content of biologically active compounds in the four selected oil blends is presented in Table 5. Blend composition had substantial effects on the profiles of these health-promoting and stability-influencing compounds.

The results presented in Table 5 demonstrate that the content of bioactive compounds in the oil blends formulated for mayonnaise production was strongly influenced by the proportion of soybean oil. Increasing the soybean oil content led to higher concentrations of tocopherols, carotenoids, and phospholipids [10], while the levels of phytosterols, squalene, and lignans progressively decreased [14,15,16]. The reduction in naturally occurring antioxidant compounds adversely affected the oxidative stability [4,6] of the oil blends, as evidenced by the results shown in Figure 2.

Table 3. Physicochemical Properties of Selected Oil Blends

Parameters	Soybean Oil : Sesame Oil : Corn Oil			
	60:30:10	70:20:10	80:10:10	90:5:5
Density (20 ℃), g/cm ³	0.9206	0.9205	0.9204	0.9202
Viscosity (20 ℃), mm ²/s	35.23	34.95	34.67	34.64
Refractive Index (20 ℃)	1.4660	1.4661	1.4662	1.4661
Iodine Value, g I_2/100 g	116.96	117.97	118.98	118.59
Saponification Value, mg KOH/g	189.52	189.52	189.52	189.41
Acid Value, mg KOH/g	0.826	0.683	0.540	0.465
Peroxide Value, mmol O_2/kg	6.27	6.46	6.65	6.73

Table 4. Fatty Acid Composition of Selected Oil Blends (% of Total Fatty Acids)

Fatty acid	Soybean Oil : Sesame Oil : Corn Oil			
	60:30:10	70:20:10	80:10:10	90:5:5
Palmitic Acid (C16:0)	9.67	9.70	9.73	9.76
Stearic Acid (C18:0)	4.93	4.71	4.49	4.45
Oleic Acid (C18:1)	28.53	27.02	25.51	24.10
Linoleic Acid (C18:2, ω-6)	51.53	52.47	53.41	54.06
Linolenic Acid (C18:3, ω-3)	5.03	5.85	6.67	7.48
Other Fatty Acids	0.31	0.25	0.19	0.15
Total	100.00	100.00	100.00	100.00

Table 5. Content of Biologically Active Compounds in the Oil Blends Prepared for Mayonnaise Formulation

Biologically active compound	Soybean Oil : Sesame Oil : Corn Oil			
	60:30:10	70:20:10	80:10:10	90:5:5
Tocopherols, mg/100 g	89.28	96.00	102.72	106.76
Phytosterols, mg/100 g	462.30	427.98	393.66	348.08
Carotenoids, mg/kg	0.57	0.60	0.63	0.615
Phospholipids, %	0.026	0.027	0.028	0.029
Squalene, mg/100 g	11.86	9.85	7.84	6.52
Lignans, mg/100 g	154.26	102.84	51.42	25.71

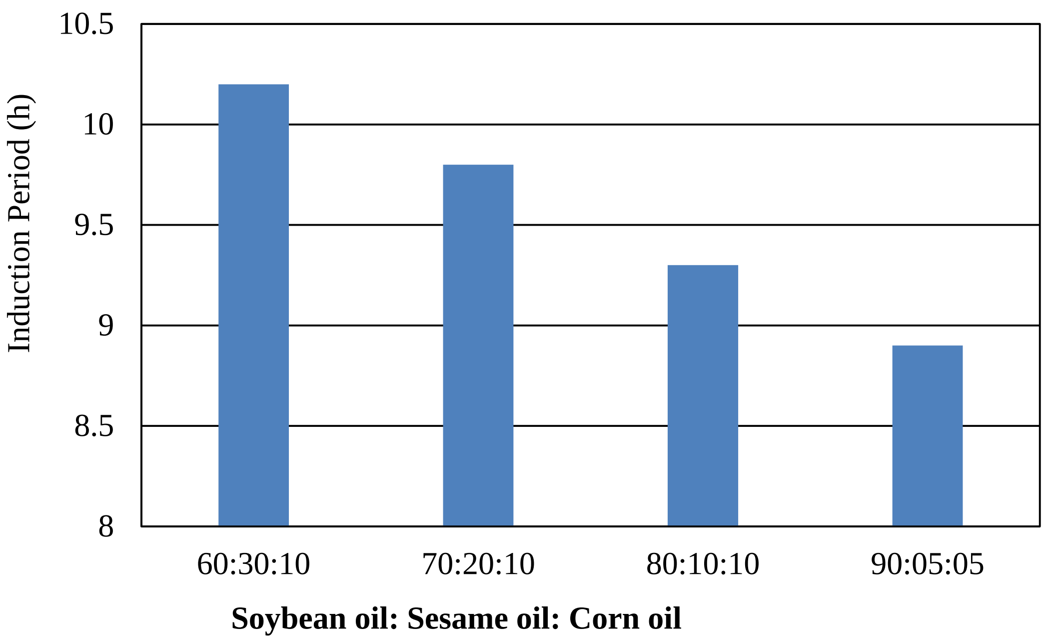

Figure 2. Oxidative Stability of the Oil Blends Prepared for Mayonnaise Formulation

3.6. Oxidative Stability During Storage

The data presented in Figure 2 indicate that the oxidative stability of the oil blends decreased as the proportion of soybean oil increased [4,6,13]. This phenomenon can be attributed to the reduction in the concentration of natural antioxidants and the simultaneous increase in the content of highly unsaturated fatty acids [4,6,24] within the blends.

Based on the above analysis, the following conclusions were drawn:

Analysis of various blends of soybean, sesame, corn, and sunflower oils revealed that the ω-3:ω-6 ratio decreased below 10:1 when the proportion of soybean oil exceeded 60%.

Since the functional properties provided by sunflower oil were also present in corn oil and sunflower oil did not play a significant role in reducing the ω-3:ω-6 ratio, it was excluded from the functional oil blend developed for mayonnaise formulation.

As the proportion of soybean oil increased in the functional oil blends, the contents of palmitic, linoleic, and linolenic acids increased, whereas the proportions of stearic, oleic, and other fatty acids decreased.

Increasing the soybean oil content resulted in higher concentrations of tocopherols, carotenoids, and phospholipids, while the levels of phytosterols, squalene, and lignans decreased. Consequently, the reduction in naturally occurring antioxidant compounds led to a decline in the oxidative stability of the oil blends.

4. Conclusions

This study successfully developed and characterized functional vegetable oil blends for mayonnaise production, systematically evaluating the relationship between blend composition, bioactive compound profiles, and oxidative stability. The following conclusions can be drawn:

Individual vegetable oils exhibited substantial differences in bioactive compound content, with corn oil showing the highest phytosterol content (870.9 mg/100 g) [14,16], soybean oil the highest tocopherol content (110.8 mg/100 g) [10], and sesame oil uniquely containing lignans (514.2 mg/100 g) [7,12,15].

Soybean oil content was the primary determinant of ω-6:ω-3 fatty acid ratio in blends, with proportions exceeding 60% required to achieve ratios below 10:1. Only soybean oil among the tested oils met recommended ω-6:ω-3 ratios (6.4:1) in its pure form [20,21].

Increasing soybean oil content in blends improved the ω-6:ω-3 ratio and increased tocopherol content but simultaneously reduced phytosterols, squalene, and lignans [14,15,16], resulting in decreased oxidative stability despite higher antioxidant vitamin content [4,6].

The optimal oil blend composition of 60:30:10 (soybean:sesame:corn) achieved a favorable ω-6:ω-3 ratio of approximately 10:1 [20,21] while maintaining acceptable oxidative stability (peroxide value 6.8 mmol O_2/kg after 180 days) without additional antioxidant supplementation [19,22].

Blends with higher soybean oil content (70:20:10 and 80:10:10) achieved more favorable ω-6:ω-3 ratios (8.7:1 and 7.9:1, respectively) but showed reduced oxidative stability, suggesting that additional antioxidant supplementation would be necessary for commercial applications requiring extended shelf life.

Sesame oil played a critical dual role in blend formulations, contributing both to fatty acid profile optimization and providing potent natural antioxidants (lignans) that substantially enhanced oxidative stability [7,12,15,25].

The development of nutritionally optimized mayonnaise with favorable omega-3 fatty acid content requires careful balancing of nutritional targets with oxidative stability considerations [1,5,13], potentially necessitating strategic use of natural antioxidants or antioxidant-rich oils like sesame oil [7,15,25].

These findings provide practical guidance for developing functional mayonnaise products that meet contemporary nutritional recommendations while maintaining acceptable quality and shelf life. The systematic approach employed in this study can be applied to other oil-based emulsion products, contributing to the broader goal of improving the nutritional quality of processed foods.

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