

Optimization of Mayonnaise Formulation with PUFA-Rich Oils: A Literature Review on Omega-6:Omega-3 Ratio Correction and Oxidative Stability

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ABSTRACT

The modern diet is critically deficient in omega-3 polyunsaturated fatty acids (PUFA n-3), as indicated by an unfavorable dietary omega-6:omega-3 ratio of about 10:1 to 30:1, far from recommended values. This literature review synthesizes studies on the formulation of mayonnaises using multiple vegetable oil sources, including sunflower, corn, flaxseed, and soybean oil to evaluate the strategies for correcting the omega-6:omega-3 ratio and ensuring product stability. The review focuses on how proportional substitution levels of these diverse oils impact the resulting fatty acid profiles (PUFA content and omega-6:omega-3 ratio) and the oxidative stability during storage, assessed mainly through PV and p-AV. Across the literature, the strategic blending of these oils, particularly the inclusion of flaxseed and soybean oil, consistently increases ALA and shifts the omega-6:omega-3 ratio toward therapeutic ranges. Crucially, while higher omega-3 levels increase susceptibility to oxidation, this challenge is reliably mitigated by optimizing the oil blend ratios and employing appropriate formulation strategies, including the use of antioxidants and specialized stabilizing agents, which generally preserve or improve oxidative stability over storage. The evidence supports mayonnaises formulated with optimized oil blends as suitable carriers to help correct essential fatty acid imbalance. The main challenge remains the need for ongoing optimization of antioxidant systems to ensure that targeted nutritional improvements are compatible with PV- and p-AV-based quality and stability requirements.

Keywords: alpha-linolenic acid, linoleic acid, peroxide value, p-anisidine value, fatty acid profiles

1. INTRODUCTION

Mayonnaise is one of the most widely consumed sauces globally, functioning as a semi-solid oil-in-water emulsion traditionally stabilized by egg yolk and containing a high percentage of vegetable oil (60-80%) (De Bruno et al, 2021). However, modern diets suffer from a critical imbalance in the omega-6:omega-3 ratio, often ranging from 10:1 to 30:1, which significantly exceeds the therapeutic recommendation (5:1 to 10:1) (Gaipova et al, 2022). Addressing this nutritional deficit requires the strategic incorporation of PUFA-rich oils into mayonnaise formulations. This enrichment effort introduces a major quality challenge: omega-3 fatty acids are highly susceptible to lipid oxidation (Khaliq et al, 2025), leading to rapid product degradation and complicating commercial viability. Since existing studies on this topic are fragmented, a comprehensive synthesis of formulation optimization strategies is necessary to effectively balance the nutritional goal omega-6:omega-3 ratio correction with chemical stability requirements.

The core argument of this review is that successful optimization of mayonnaise formulation for omega-6:omega-3 ratio correction is critically dependent on the strategic use of PUFA oils complemented by precisely adjusted antioxidant systems and stabilizing agents to effectively

maintain oxidative stability (Peroxide Value (PV) and p-Anisidine Value (p-AV)) throughout storage. This review specifically focuses on studies concerning the formulation of mayonnaise using PUFA oils (flaxseed, soybean, corn, and sunflower) and evaluates two primary quality domains: the fatty acid profile (omega-6:omega-3 ratio) and oxidative stability (measured by PV and p-AV). By integrating evidence that explicitly links PUFA substitution levels with the omega-6:omega-3 target, primary degradation (PV), and secondary degradation (p-AV), this work offers a novel, comprehensive formulation strategy for the food industry. To achieve this, the paper is organized as follows: Chapter 2 presents the literature review on omega-3/omega-6 physiology, vegetable oil fatty acid profiles, mayonnaise formulation, and oxidative stability; Chapter 3 describes the methods used for collecting and screening the literature; Chapter 4 presents the main findings on fatty acid profiles and stability; Chapter 5 offers an in-depth discussion, including implications, limitations, and formulation recommendations; and Chapter 6 concludes with key insights and directions for future research.

2. LITERATURE REVIEW

Omega-3 and omega-6 are essential fatty acids that act as precursors for eicosanoids regulating inflammation and vascular function, and modern diets with omega-6:omega-3 ratios far above ancestral or recommended ranges are associated with elevated cardiometabolic risk, suggesting a need to reduce this ratio through increased omega-3 intake and moderated omega-6 exposure (DiNicolantonio et al., 2018). Vegetable oils differ substantially in composition, with soybean, sunflower, and corn oils rich in linoleic acid (LA, omega-6) and flaxseed oil particularly high in alpha-linolenic acid (ALA, omega-3) (Deol et al., 2016; He et al., 2017; Ivanova et al., 2016), so that blending these oils allows intentional modulation of the omega-6:omega-3 ratio and total PUFA content in the fat phase of foods such as mayonnaise (Memon et al., 2024).

Mayonnaise, typically containing 60-80% oil in an oil-in-water emulsion, therefore provides a practical matrix for rebalancing essential fatty acid intake, but the higher unsaturation that improves nutritional quality also increases susceptibility to lipid oxidation, usually monitored through peroxide value (PV) for primary oxidation and p-anisidine value (p-AV) for secondary aldehydic products (Ghelichi et al., 2023). Prior studies show that substituting part of the base oil with high-ALA oils like flaxseed or incorporating structured PUFA-rich particles can markedly improve fatty acid profiles and move the omega-6:omega-3 ratio toward therapeutic ranges, while appropriate use of endogenous and added antioxidants, encapsulation technologies, and refrigerated storage can keep PV and p-AV within regulatory and sensory-acceptable limits over typical shelf-life periods (El-Waseif et al., 2022; Rahim et al., 2024).

Across prior literature on PUFA-enriched emulsions, key research gaps persist for mayonnaise applications. Few studies integrate fatty acid profile data (TSFA, ALA, TUFAs, ω -6: ω -3 ratios) with PV/p-AV stability to define optimal formulation criteria. Secondary oxidation (p-AV) evaluation remains underexplored relative to ALA levels. To address these gaps, the proposed framework integrates three elements for PUFA-enriched mayonnaise: (1) nutritional optimization targeting omega-6:omega-3 ratios $\leq 10:1$; (2) rational blending of flaxseed/soybean/sunflower/corn oils to enhance PUFA; and (3) evaluating oxidative stability focuses on controlling lipid oxidation by leveraging intrinsic antioxidants naturally present in certain oils (such as phenolic compounds and flavonoids in flaxseed), supplementing them with added stabilizing agents (such as sesame-derived components), and applying cold storage conditions to keep peroxide value (PV) and p-anisidine value (p-AV) within acceptable regulatory and quality limits throughout the product's intended shelf life.

3. METHODS

This literature review systematically synthesizes studies on omega-3-enriched mayonnaise formulations. Data were sourced from major scientific databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar, using combinations of keywords such as “mayonnaise,” “PUFA vegetable oil,” “oxidative stability,” and “fatty acid profile.” The search was restricted to English-language experimental papers published in approximately the last 10 years that reported quantitative data on fatty acid profiles and oxidative stability indicators, primarily peroxide value (PV) and p-anisidine value (p-AV).

4. FINDINGS

In El-Wasseif et al. (2022), mayonnaise was formulated by replacing soybean oil (70% in control with 15% vinegar, 10% egg yolk, 3% sugar, 2% salt) with flaxseed oil at 20% (MFXS1), 30% (MFXS2), and 40% (MFXS3) via gradual emulsification, stored at $25\pm 5^{\circ}\text{C}$ (ambient) and $7\pm 2^{\circ}\text{C}$ (cold) for 12 weeks with biweekly analysis. Flaxseed substitution significantly reduced total saturated fatty acids (TSFA) from 20.63% to 17.52%, 14.51%, and 12.34% respectively, primarily lowering palmitic (C16:0, 5-13.20%) and stearic (C18:0, 4.18-4.45%) acids with no trans fatty acids detected (consistent with U.S. ranges 0-2.2%), while alpha-linolenic acid (ALA, ω -3 C18:3) rose dramatically from 6.50% to 18.38%, 24.02%, and 37.87%, driving total unsaturated fatty acids (TUFA) to 82.48-87.66% for enhanced therapeutic profiles. Consistent with these compositional shifts, the calculated omega-6:omega-3 ratios (based on C18:2 n-6/C18:3 n-3) improved from about 7.7:1 in the control to approximately 2.5:1, 1.6:1, and 0.8:1 in MFXS1-MFXS3, indicating a progressive transition from an imbalanced to a strongly omega-3–dominant fatty acid profile as flaxseed substitution increased.

Oxidative stability showed PV increasing significantly over time (faster at ambient due to oil-water interface peroxidation), reaching 5.98, 6.10, 6.17, 6.22 meq O_2/kg (MFXS1-3/control, ambient) and 4.12, 4.20, 4.57, 4.19 meq O_2/kg (cold) after 12 weeks, all below Egyptian limit <15 meq O_2/kg , with flaxseed samples exhibiting slightly lower PV than control at room temperature due to natural phenolics/flavonoids retarding early oxidation. p-AV progressively rose reflecting primary peroxides decomposing into secondary aldehydes (2-alkenals), proportional to unsaturation degree (higher in ALA-rich samples), though refrigeration substantially mitigated both PV and p-AV progression.

In Gaipova et al. (2022), sunflower:corn:soybean blends targeted ω -6: ω -3 ratios of 5-10:1 (soybean providing ALA at 7.95%, sunflower 67.85% LA, corn 61.51% LA), identifying 20:20:60 (ratio 12:1, stable) and 10:20:70 (ratio 10:1, optimal but unstable) mixtures; peroxide values rose over 90 days with control (oil just from sunflower) at 6.2 meq/kg (<10 standard), most blends >10 except sample 1 (~ 9.8), and p-AV lowest in control due to soybean's oxidation tendency despite linolenic contribution. Sesame seed powder addition (1-5% replacing cornstarch) reduced PV below 10 meq/kg after 90 days, with formulations containing 3-5% sesame achieving stability standards alongside the 10:20:70 oil ratio.

Table 1. Comparative fatty acid profile and oxidative stability of PUFA-enriched mayonnaise from two key studies

Parameter	El-Wasseif et al. (2022)	Gaipova et al. (2022)
Oil sources & substitution	Soybean oil in the oil phase partially replaced with flaxseed oil at 20% (MFXS1), 30% (MFXS2), and 40% (MFXS3)	Mayonnaise prepared with blends of sunflower, corn, and soybean oils; main ratios tested 20:20:60 (ω -6: ω -3 \approx 12:1) and 10:20:70 (ω -6: ω -3 \approx 10:1)
Saturated fatty acids (TSFA)	Decreased from 20.63% in the control to 17.52% (MFXS1), 14.51% (MFXS2), and 12.34% (MFXS3); palmitic acid (C16:0) and stearic acid (C18:0) were the main contributors	Not fully reported numerically for mayonnaise samples
ALA (ω -3 C18:3)	Increased from 6.50% of total fatty acids in the control to 18.38% (MFXS1), 24.02% (MFXS2), and 37.87% (MFXS3)	ω -3 supplied mainly by soybean oil (C18:3 n-3 \approx 7.95% in soybean oil), contributing to ω -6: ω -3 ratios of 12:1 (20:20:60) and 10:1 (10:20:70) of sunflower, corn, and soybean oils ratio
Total unsaturated fatty acids (TUFA)	Increased with flaxseed substitution, reaching about 82.48–87.66% in flaxseed-enriched samples compared with the control	Not directly tabulated for mayonnaise
ω -6: ω -3 ratio in mayonnaise	Improved from \sim 7.7:1 in the control to \sim 2.5:1 (MFXS1), \sim 1.6:1 (MFXS2), and \sim 0.8:1 (MFXS3)	Oil blends designed to yield ω -6: ω -3 \approx 12:1 (20:20:60) and 10:1 (10:20:70) of sunflower, corn, and soybean oils ratio
PV at end of storage	Ambient: 5.98–6.22 meq/kg; Cold: 4.12–4.57 meq/kg (all <15)	Control \sim 6.2 meq/kg; blends >10 meq/kg without sesame; <10 meq/kg with sesame
p-AV trend	Increased over time, higher in ALA-rich samples; slowed by cold storage	Lowest in control; higher in blends
Overall stability outcome	Stable with flaxseed phenolics + refrigeration	Unstable without sesame; improved with addition

The comparative findings from El-Wasseif et al. (2022) and Gaipova et al. (2022), as detailed in Table 1, highlight distinct strategies for PUFA-enriched mayonnaise. Flaxseed oil substitution in El-Wasseif's work reduced TSFA to 12.34% (MFXS3) while boosting ALA to 37.87% and TUFA to 87.66%, achieving ω -6: ω -3 ratios as low as 0.8:1 with PV remaining stable at 5.98–6.22 meq/kg (ambient) or 4.12–4.57 meq/kg (cold), thanks to flaxseed's natural flavonoids. In contrast, Gaipova's sunflower:corn:soybean blends targeted ω -6: ω -3 ratios of 10–12:1 but exhibited PV >10 meq/kg after 90 days without sesame powder, which restored stability below 10 meq/kg.

These results reveal a key trade-off: elevated ALA/PUFA levels improve nutrition but heighten peroxidation risks at emulsion interfaces, mitigated most simply by refrigeration, which consistently limited PV rises. Gaipova's reliance on added sesame antioxidants underscores soybean's oxidative vulnerability despite ratio tuning, while El-Wasseif's flaxseed approach demonstrates "self-protection" from inherent phenolics, favoring such single-source oils for vegetable-based functional products in warm climates where ambient storage promotes secondary aldehydes (p-AV) proportional to unsaturation. Study limitations include the absence of long-term monitoring (>90 days), lack of exploration of other high-PUFA oils such as sacha inchi particularly its superior omega-3 content (44.3–51.62% ALA) (Lu et al., 2025), and absence of industrial-scale validation under high-shear production conditions.

5. DISCUSSION

The combined findings from El-Wasseif et al. (2022) and Gaipova et al. (2022), as summarized in Table 1, demonstrate that vegetable oil-based mayonnaise can achieve PUFA enrichment through targeted substitutions, but success hinges on oil selection, blending ratios, and antioxidant strategies. El-Wasseif's: 20-40% flaxseed oil replacement reduced TSFA to 12.34%, elevated ALA to 37.87%, and maintained PV at 5.98-6.22 meq/kg (ambient) or 4.12-4.57 meq/kg (cold), with natural flavonoids providing inherent protection. Gaipova's: sunflower:corn:soybean blends (ω -6: ω -3 \approx 10-12:1) exceeded PV limits (>10 meq/kg after 90 days) without sesame powder, which restored stability below 10 meq/kg, highlighting soybean's oxidative vulnerability. These results align with emulsion oxidation theory. Higher unsaturation (TUFA $>87\%$ in flaxseed) speeds up primary (PV) and secondary (p-AV) oxidation at oil-water interfaces, proportional to double bonds and storage temperature. Flaxseed phenolics delay hydroperoxide formation like natural antioxidants in literature, while Gaipova's sesame acts as external stabilizer against PUFA blend instability.

The studies directly address key questions: (1) 20-40% ALA-rich oil substitution optimizes profiles (ω -6: ω -3 down to 0.8:1) with PV/p-AV within limits under refrigeration; (2) oxidation is mitigated by intrinsic phenolics (flaxseed) or additives (sesame) in PUFA blends; (3) commercial barriers include cold chain needs and blend control for nutrition-stability balance, favoring single-source ALA oils over multi-blends. Findings advance PUFA emulsion theory by validating "self-protected" high-ALA oils for functional foods, shifting from complex blends to phenolic-rich sources in tropical contexts, and emphasizing temperature as a primary mitigator of peroxidation kinetics. Both works are lab-scale with short-term data (90 days/12 weeks), industrial shearing, and tropical ambient shelf life without cold chain, necessitating caution in scaling and calls for extended trials.

6. CONCLUSION

This literature review demonstrates that vegetable oil-based mayonnaise formulations successfully enrich omega-3 PUFA content through ALA-rich oil substitutions (20-40%) or multi-oil blending, achieving therapeutic ω -6: ω -3 ratios (0.8:1 to 12:1) while maintaining oxidative stability via PV and p-AV monitoring under cold storage and antioxidants. Higher unsaturation improves nutrition but requires mitigation through natural phenolics, added stabilizers like sesame, and refrigeration ($\leq 7^\circ\text{C}$) to keep PV <10 -15 meq/kg over 12+ weeks, positioning mayonnaise as a practical functional food carrier. Commercial strategies should emphasize 20-30% ALA oils with cold chain logistics and routine testing in tropical markets; future research needs industrial-scale validation of high-shear effects, and long-term ambient shelf life.

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