

Type Chemical Composition of Estragole-Linalool-Type *Ocimum Basilicum* Essential Oil and Oxidative Stability of Multioil Margarine Prototypes

Anicet Frédéric Binaki^{1,2}, Eliane Thérèse Biassala¹, Jeantia Matoko Badila¹,
Koukel-Jemero Loemba-Mouely¹, Mignon Prince Exaucé Taty¹,
Célestine Kiminou Ngounga^{1,2}, Bob Wilfrid Loumouamou^{1,2,*}, Hubert Makomo³

¹Food Chemistry and Technology Laboratory & Faculty of Science and Technology, Marien Ngouabi University, Brazzaville, Republic of the Congo

²Process Engineering Laboratory & UNESCO-ENSP Chair, Marien Ngouabi University, Brazzaville, Republic of the Congo

³Plant and Life Chemistry Unit & Faculty of Science and Technology, Marien Ngouabi University, Brazzaville, Republic of the Congo

Abstract This study characterized the leaf essential oil of *Ocimum basilicum* and examined its effect on the storage stability of multioil margarine prototypes prepared with either water or watermelon-seed milk as the aqueous phase. The essential oil was analysed by gas chromatography with flame-ionization detection and gas chromatography-mass spectrometry. Six prototypes containing *Irvingia gabonensis* (24.14%), *Moringa oleifera* (43.83%) and *Citrullus lanatus* (13.05%) oils were prepared without added antioxidant, with *O. basilicum* essential oil (0.02%), or with ascorbic acid (0.02%), and monitored for 49 days at ambient laboratory conditions. Forty-two volatile constituents accounted for 99.998% of the chromatographic profile. Estragole (40.665%), linalool (36.079%) and 1,8-cineole (12.757%) were predominant and together represented 89.501% of the oil. At day 49, peroxide values were 35, 25 and 15 meq O₂ kg⁻¹ in the water-based control, essential-oil and ascorbic-acid prototypes, respectively, compared with 42, 35 and 18 meq O₂ kg⁻¹ in the corresponding seed-milk prototypes. Essential-oil addition reduced the final peroxide value by 28.6% in the water system and 16.7% in the seed-milk system relative to their controls, whereas ascorbic acid produced a 57.1% reduction in both matrices. The essential oil did not lower the final acid value in the water system and produced only a 5.6% reduction in the seed-milk system. The results identify an estragole-linalool chemotype and show a modest, matrix-dependent protection against primary oxidation at 0.02%, inferior to that of ascorbic acid under the tested conditions. Because the oil was estragole-rich, food application requires chemotype selection and compositional control.

Keywords *Ocimum basilicum*, Estragole, Linalool, Essential oil, Lipid oxidation, Margarine

1. Introduction

Margarines and related water-in-oil emulsions are susceptible to oxidative deterioration during processing and storage. Lipid oxidation generates hydroperoxides and subsequently volatile products that impair flavour, nutritive quality and shelf life. The interfacial organization of emulsions, the distribution of pro- and antioxidants, and interactions with the aqueous phase can make oxidation behaviour differ substantially from that of bulk oils. [1,2,3,4]

Underutilized tropical oilseeds provide complementary lipid resources for formulated fats. Watermelon (*Citrullus lanatus*), moringa (*Moringa oleifera*) and African bush mango

(*Irvingia gabonensis*) yield oils with distinct physicochemical and fatty-acid characteristics, while watermelon seeds may also be processed into a milk-like aqueous dispersion. [6,23,24,25,30]

Plant essential oils and botanical extracts are investigated as natural sources of compounds capable of slowing lipid oxidation. Basil (*Ocimum basilicum*) essential oil is chemically variable, and its activity therefore depends on chemotype, concentration and food matrix. Linalool, estragole, 1,8-cineole and other terpenoids commonly contribute to its profile, but their relative abundance varies with origin and growing conditions. [5,7,8,9,10,11,12,13,14]

The present work aimed (i) to establish the GC-FID and GC-MS profile of basil leaf essential oil obtained in Brazzaville, Republic of the Congo, and (ii) to compare the peroxide- and acid-value trajectories of multioil margarine prototypes made with water or watermelon-seed milk and containing no antioxidant, 0.02% basil essential oil, or 0.02%

* Corresponding author:

bwlumwahamu@gmail.com (Bob Wilfrid Loumouamou)

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ascorbic acid.

2. Experimental

2.1. Raw Materials

Watermelon (*C. lanatus*) seeds originating from Madingou (Bouenza Department) were purchased at Total Market in Bacongo, Brazzaville. Moringa (*M. oleifera*) seeds were obtained in Brazzaville, and African bush mango (*I. gabonensis*) kernels originating from Ouessou (Sangha Department) were purchased at Ouenzé Market. Fresh basil (*O. basilicum*) leaves were collected at Nzaba in the Madibou district of Brazzaville.

2.2. Preparation of Oils, Watermelon-Seed Milk and Essential Oil

The three lipid materials were obtained by mechanical pressing and filtered through muslin. The *I. gabonensis* kernel paste was gently warmed before pressing; the *M. oleifera* and *C. lanatus* seeds were pressed directly. For the aqueous dispersion, 300 g of watermelon seeds were soaked for 16 h, heated at 100–110 °C for 10 min, ground with 1 L of water and filtered through muslin.

Fresh basil leaves were sorted, washed, drained and hydrodistilled. The distillate was extracted with diethyl ether; the organic phase was dried over anhydrous sodium sulfate, filtered and stored in an amber container until analysis.

2.3. GC-FID Analysis

Fresh basil leaves were sorted, washed, drained and hydrodistilled.

Quantitative profiling was performed on an Agilent 6890 gas chromatograph fitted with a DB-5 capillary column (20 m × 0.18 mm i.d.; film thickness, 0.18 µm) and a flame-ionization detector. The oven was held at 50 °C for 3.2 min and then programmed to 300 °C at 10 °C min⁻¹. The injector temperature was 280 °C. Hydrogen was used as the carrier gas at 1 mL min⁻¹; detector gas flows were 40 mL min⁻¹ hydrogen and 450 mL min⁻¹ air. Relative percentages were obtained by peak-area normalization. Two injections were performed.

2.4. GC-MS Analysis and Compound Identification

Qualitative analysis was performed with an Agilent 7890 gas chromatograph coupled to an Agilent 5975 mass spectrometer and equipped with a DB-5 column of the same dimensions. The oven was held at 50 °C for 3.2 min and then programmed to 300 °C at 8 °C min⁻¹; the injector was maintained at 280 °C. Electron-impact ionization was operated at 70 eV and helium carrier gas at 0.9 mL min⁻¹. Components were assigned by comparing mass spectra and reported retention indices with Adams, NIST 2008, MassFinder and the LEXVA Analytique laboratory databases. [18,19,20,21,22]

2.5. Initial Physicochemical Measurements

Peroxide value (PV) and acid value (AV) of the pressed oils were determined by standardized titrimetric procedures and expressed as meq O₂ kg⁻¹ and mg KOH g⁻¹, respectively. The measurements were performed in triplicate. The pH and titratable acidity of the watermelon-seed milk were also measured; titratable acidity was expressed in Dornic degrees (°D). [15,16,17]

2.6. Margarine Formulation and Storage

The fat blend contained 24.14% *I. gabonensis* oil, 43.83% *M. oleifera* oil and 13.05% *C. lanatus* oil (81.02% total). The aqueous phase was water or watermelon-seed milk (17%). Egg-yolk-derived emulsifier was included at 1.63–1.65%, sodium chloride at 0.35%, and antioxidant treatment at 0, 0.02% basil essential oil or 0.02% ascorbic acid. The six formulations are summarized in Table 1.

The fat and aqueous phases were combined at 60 °C under magnetic stirring for 15 min. The mixture was emulsified using an electric beater, cooled on ice to induce crystallization, kneaded to obtain a smooth product, packed in airtight 100-g plastic containers and stored under ambient laboratory conditions for 49 days. PV and AV were recorded weekly.

2.7. Data Treatment

Physicochemical measurements are reported as mean ± standard deviation (n = 3). Essential-oil percentages are the mean of two GC-FID injections. Weekly storage values are presented descriptively because independent batch replication was not documented in the dataset. Final-day percentage changes were calculated against the corresponding antioxidant-free matrix control. No inferential statistics were applied to the storage series.

Table 1. Experimental design for the six margarine prototypes

Code	Aqueous phase (17%)	Antioxidant	Level (%)	Other constituents (%)
WC	Water	None	0	Fat blend 81.02; emulsifier 1.63; NaCl 0.35
WE	Water	Basil essential oil	0.02	Fat blend 81.02; emulsifier 1.63; NaCl 0.35
WA	Water	Ascorbic acid	0.02	Fat blend 81.02; emulsifier 1.63; NaCl 0.35
MC	Watermelon-seed milk	None	0	Fat blend 81.02; emulsifier 1.65; NaCl 0.35
ME	Watermelon-seed milk	Basil essential oil	0.02	Fat blend 81.02; emulsifier 1.63; NaCl 0.35
MA	Watermelon-seed milk	Ascorbic acid	0.02	Fat blend 81.02; emulsifier 1.63; NaCl 0.35

WC, water control; WE, water + essential oil; WA, water + ascorbic acid; MC, seed-milk control; ME, seed milk + essential oil; MA, seed milk + ascorbic acid

3.1. Initial Characteristics of the Lipid and Aqueous Ingredients

(Table 2). *C. lanatus* oil had the lowest PV (3.10 ± 0.29 meq $\text{O}_2 \text{ kg}^{-1}$), whereas *M. oleifera* oil had a PV of 12.83 ± 0.65 meq $\text{O}_2 \text{ kg}^{-1}$. AV varied less, from 2.96 ± 0.42 to 3.73 ± 0.44 mg KOH g^{-1} . These values describe the materials before blending and therefore provide the relevant baseline for interpreting the formulated system.

Material	PV (meq O ₂ kg ⁻¹)	AV (mg KOH g ⁻¹)	Aqueous-phase property
C. lanatus oil	3.10 ± 0.29	2.96 ± 0.42	—
M. oleifera oil	12.83 ± 0.65	3.66 ± 0.48	—
I. gabonensis oil	4.23 ± 0.64	3.73 ± 0.44	—
Watermelon-seed milk	—	—	pH 6.65 ± 0.10; acidity 16.66 ± 0.44 [‡]

Table 3. GC-FID and GC-MS composition of *Ocimum basilicum* leaf essential oil

No.	Compound	Rl _{exp}	Rl _{lit}	Inj. 1 (%)	Inj. 2 (%)	Mean (%)
1	α -Pinene	935	932	0.369	0.369	0.369
2	Camphene	952	946	0.073	0.073	0.073
3	Sabinene	975	969	0.386	0.387	0.387
4	β -Pinene	980	974	0.859	0.859	0.859
5	1-Octen-3-ol	984	974	0.065	0.064	0.065
6	Myrcene	990	988	0.279	0.277	0.278
7	Limonene	1032	1024	0.988	0.990	0.989
8	1,8-Cineole	1037	1026	12.761	12.753	12.757
9	(Z)- β -Ocimene	1047	1032	0.586	0.588	0.587
10	γ -Terpinene	1060	1054	0.061	0.061	0.061
11	cis-Linalool oxide	1075	1067	0.168	0.164	0.166
12	Terpinolene	1087	1086	0.105	0.105	0.105
13	trans-Linalool oxide	1089	1084	0.055	0.054	0.055
14	Linalool	1107	1095	36.089	36.069	36.079
15	(E)-Myroxide	1144	1140	0.127	0.124	0.126
16	Camphor	1159	1141	1.566	1.565	1.566
17	δ -Terpineol	1181	1162	0.193	0.193	0.193
18	Terpinen-4-ol	1191	1174	0.213	0.213	0.213
19	Estragole (methyl chavicol)	1214	1195	40.673	40.657	40.665
20	Citronellol	1233	1223	0.213	0.214	0.214
21	Neral	1248	1235	0.111	0.109	0.110
22	Geraniol	1258	1249	0.322	0.315	0.319
23	Geranial	1277	1264	0.159	0.157	0.158
24	Geranyl acetate	1383	1379	0.084	0.083	0.084
25	α -Copaene	1385	1374	0.068	0.067	0.068
26	β -Elemene	1397	1385	0.191	0.191	0.191
27	trans- α -Bergamotene	1440	1432	0.932	0.930	0.931
28	(Z)- β -Farnesene	1456	1444	0.050	0.048	0.049
29	α -Humulene	1469	1452	0.063	0.061	0.062
30	Muurola-4(14),5-diene	1475	1465	0.056	0.056	0.056
31	Germacrene D	1494	1484	0.228	0.226	0.227
32	Bicyclogermacrene	1509	1500	0.062	0.061	0.062
33	α -Bulnesene	1513	1509	0.037	0.036	0.037
34	γ -Cadinene	1526	1513	0.298	0.302	0.300

35	δ -Cadinene	1529	1522	0.095	0.097	0.096
36	β -Sesquiphellandrene	1533	1521	0.090	0.093	0.092
37	α -Bisabolene	1548	—	0.228	0.229	0.229
38	Elemol	1562	1548	0.185	0.185	0.185
39	epi-Cubenol	1632	—	0.120	0.119	0.120
40	epi- α -Cadinol	1659	—	0.755	0.758	0.757
41	α -Cadinol	1673	1652	0.034	0.057	0.046
42	α -Eudesmol	1675	1652	ND	0.039	0.020
	Total identified			99.997	99.998	99.998

R_{exp}, experimental retention index on DB-5; *R_{lit}*, literature retention index; *Inj.*, injection; ND, not detected. Mean values are based on two injections; ND was treated as zero when calculating the mean for α -eudesmol.

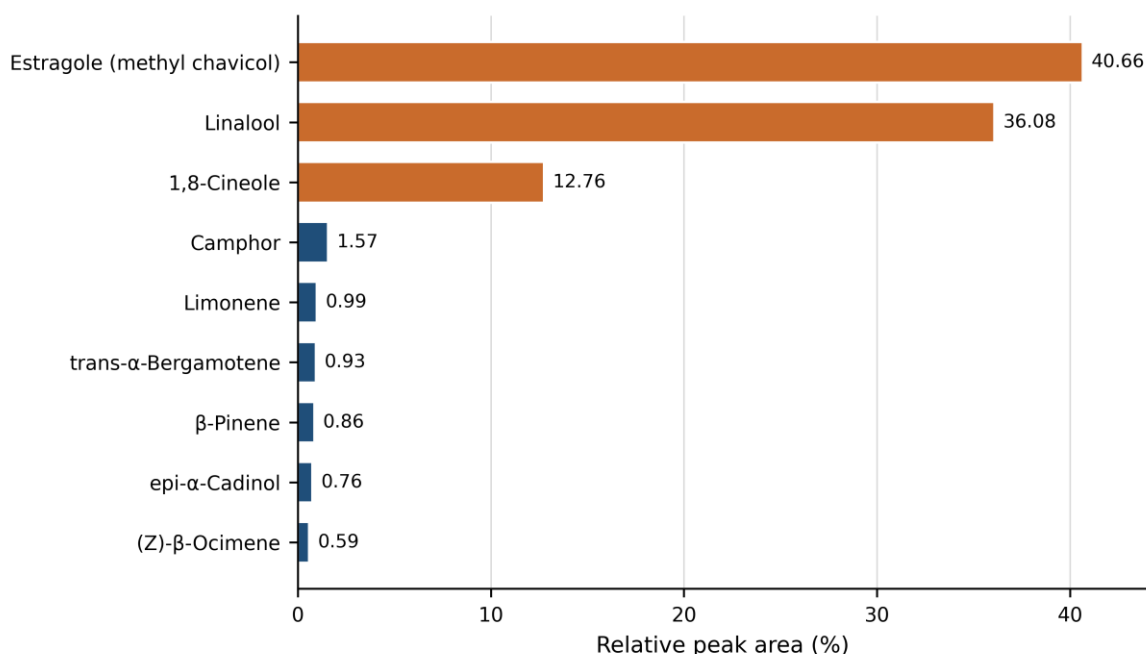


Figure 1. Major constituents ($\geq 0.50\%$) of *O. basilicum* leaf essential oil. Values are mean relative peak areas from two GC-FID injections

3.2. Essential-Oil Composition and Chemotype

The GC-FID profile comprised 42 constituents and represented 99.998% of the detected peak area (Table 3). Estragole (40.665%), linalool (36.079%) and 1,8-cineole (12.757%) dominated and together accounted for 89.501%. The next most abundant constituents were camphor (1.566%), limonene (0.989%), trans- α -bergamotene (0.931%), β -pinene (0.859%) and epi- α -cadinol (0.757%) (Figure 1).

By chemical class, phenylpropanoids represented 40.665%, oxygenated monoterpenes 52.037%, monoterpene hydrocarbons 3.708%, sesquiterpene hydrocarbons 2.397%, oxygenated sesquiterpenes 1.126% and other compounds 0.065%. The co-dominance of estragole and linalool supports classification as an estragole–linalool type. This profile is consistent with the pronounced chemical polymorphism reported for basil oils, in which genotype and environmental conditions influence the balance between phenylpropanoids and terpenoids. [10,11,12]

3.3. Development of Peroxide Value During Storage

PV increased throughout storage in every formulation (Table 4 and Figure 2A). At day 49, the water-based control reached 35 meq O₂ kg⁻¹, compared with 25 meq O₂ kg⁻¹ for the essential-oil treatment and 15 meq O₂ kg⁻¹ for the ascorbic-acid treatment. Thus, relative to the water-based control, basil essential oil and ascorbic acid reduced the final PV by 28.6% and 57.1%, respectively.

The seed-milk formulations followed the same ranking but showed higher final PV values: 42 meq O₂ kg⁻¹ for the control, 35 meq O₂ kg⁻¹ with essential oil and 18 meq O₂ kg⁻¹ with ascorbic acid. The corresponding reductions were 16.7% and 57.1%. Replacing water with watermelon-seed milk increased the day-49 PV by 20% in the control, 40% in the essential-oil treatment and 20% in the ascorbic-acid treatment.

The lower relative efficacy of basil essential in the seed-milk system (16.7% PV reduction versus 28.6% in the water

system) indicates clear matrix dependence. This behavior is compatible with interfacial oxidation mechanisms in which antioxidant effectiveness depends on partitioning and localization at the oil–water interface. The seed-milk phase introduces additional dispersed constituents and may modify antioxidant partitioning and/or promote pro-oxidant interactions; accordingly, efficacy observed in the water system cannot be directly extrapolated to the seed-milk system. [4,26,27]

3.4. Development of Acid Value During Storage

AV also increased progressively (Table 5 and Figure 2B), but the essential oil did not reproduce its PV effect. In the

water system, the day-49 AV was 6.5 mg KOH g^{−1} for the control and 6.8 mg KOH g^{−1} with essential oil, a 4.6% increase rather than a reduction. In the seed-milk system, essential oil lowered the final AV only from 7.2 to 6.8 mg KOH g^{−1} (5.6%). Ascorbic acid produced lower final values of 4.5 and 5.0 mg KOH g^{−1}, reductions of 30.8% and 30.6% relative to the corresponding controls.

PV and AV track different deterioration processes: PV reflects primary lipid hydroperoxides, whereas AV reflects free fatty acids generated mainly by hydrolysis. The contrast between the two indices therefore indicates that the basil oil at 0.02% modestly slowed peroxide accumulation but did not consistently inhibit hydrolytic change.

Table 4. Peroxide value of margarine prototypes during 49 days of storage (meq O₂ kg^{−1})

Formulation	W0	W1	W2	W3	W4	W5	W6	W7
WC	0	2	4	8	12	18	25	35
WE	0	2	4	7	10	15	20	25
WA	0	1	2	4	6	9	12	15
MC	0	3	5	9	14	22	30	42
ME	0	2	4	8	12	18	25	35
MA	0	1	2	5	7	10	13	18

W0–W7, storage weeks 0–7. Formulation codes are defined in Table 1.

Table 5. Acid value of margarine prototypes during 49 days of storage (mg KOH g^{−1})

Formulation	W0	W1	W2	W3	W4	W5	W6	W7
WC	0.5	1.2	2.5	3.5	4.2	5.0	5.8	6.5
WE	0.5	1.3	2.7	3.8	4.5	5.3	6.0	6.8
WA	0.3	0.8	1.5	2.2	2.8	3.5	4.0	4.5
MC	0.6	1.5	3.0	4.0	4.8	5.8	6.5	7.2
ME	0.5	1.3	2.8	3.7	4.3	5.2	6.0	6.8
MA	0.4	1.0	2.0	2.5	3.0	3.8	4.5	5.0

W0–W7, storage weeks 0–7. Formulation codes are defined in Table 1.

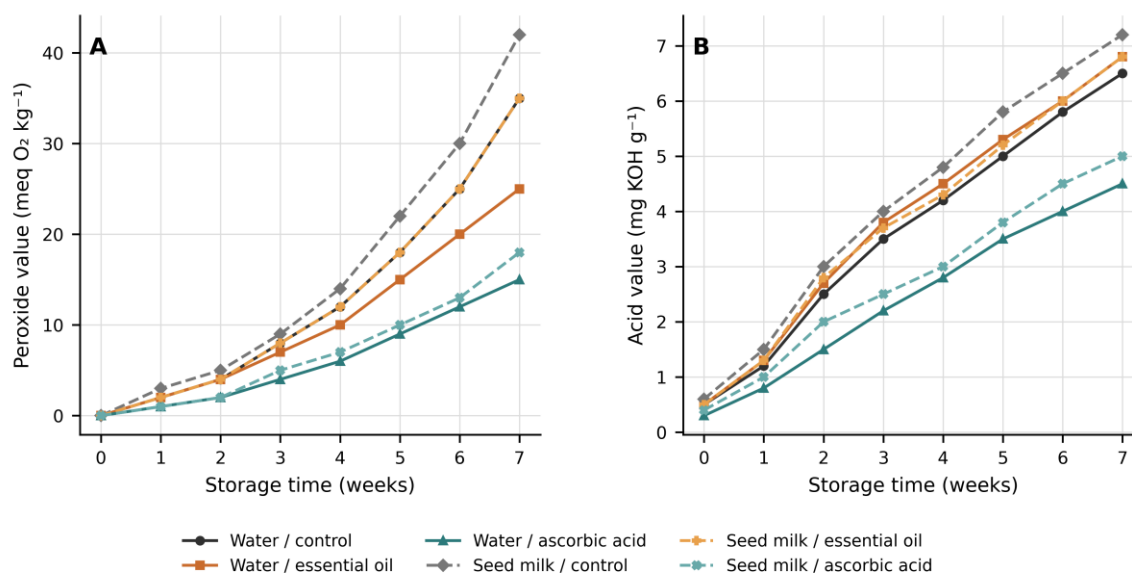


Figure 2. Peroxide-value (A) and acid-value (B) profiles of water- and watermelon-seed-milk margarine prototypes during storage. Lines connect the observed weekly values; no inferential error bars are shown because independent batch replication was not documented

3.5. Performance and Food-Use Considerations

The tested essential oil provided partial protection against primary oxidation, whereas ascorbic acid consistently provided greater protection at the same nominal inclusion level. Oxygenated monoterpenes represented 52.037% of the essential oil, with linalool accounting for 36.079%; their abundance may have contributed to radical-scavenging and/or synergistic effects. However, the present compositional data do not allow the observed antioxidant response to be attributed to any single constituent. [13,14]

The 0.02% essential-oil formulation, combined with the measured estragole proportion of 40.665%, corresponds to a nominal estragole input of approximately 81 mg kg⁻¹ before processing and storage losses. This value is a formulation estimate and should not be interpreted as the residual estragole concentration in the finished product. Because estragole has raised genotoxicity and carcinogenicity concerns, and European evaluations recommend minimizing exposure where practical, further food development should prioritize low-estragole basil chemotypes, quantify residual estragole after processing and storage, and establish product-specific safety before any commercialization claim is made. [28,29]

The present data establish composition and descriptive storage trajectories but do not document independent formulation batches, sensory acceptance, microbiological stability or volatile retention after processing. These endpoints, together with replicated storage trials, are required to define technological relevance and shelf life.

4. Conclusions

Basil leaf essential oil from Brazzaville was characterized as an estragole–linalool chemotype, dominated by estragole (40.665%), linalool (36.079%), and 1,8-cineole (12.757%). At 0.02%, the oil reduced the day-49 peroxide value (PV) by 28.6% in the water-based prototype and by 16.7% in the watermelon-seed-milk prototype, whereas ascorbic acid produced a 57.1% reduction in both matrices. In contrast, the essential oil did not reduce the final acid value (AV) in the water system and lowered it by only 5.6% in the seed-milk system, indicating a greater effect on primary oxidation than on hydrolytic deterioration. The weaker protection observed in the seed-milk matrix suggests that antioxidant efficacy was influenced by matrix-dependent partitioning at the oil–water interface and by possible pro-oxidant interactions with aqueous-phase constituents. These results demonstrate modest, matrix-dependent antioxidant activity at 0.02% and indicate that efficacy observed in one emulsion matrix should not be directly extrapolated to another. Because the essential oil was rich in estragole, further food applications should prioritize low-estragole chemotypes and include verification of residual estragole levels in the finished product before any safety or commercialization claims are made.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data used in this study are included in the article.

REFERENCES

- [1] Codex Alimentarius Commission, Standard for Fat Spreads and Blended Spreads, CXS 256-2007, amended 2024.
- [2] F. Shahidi and Y. Zhong, Lipid oxidation and improving the oxidative stability, *Chem. Soc. Rev.*, 2010, 39, 4067–4079. <https://doi.org/10.1039/B922183M>.
- [3] E. Choe and D. B. Min, Mechanisms and factors for edible oil oxidation, *Compr. Rev. Food Sci. Food Saf.*, 2006, 5, 169–186. <https://doi.org/10.1111/j.1541-4337.2006.00009.x>.
- [4] D. J. McClements and E. A. Decker, Lipid oxidation in oil-in-water emulsions: impact of molecular environment on chemical reactions in heterogeneous food systems, *J. Food Sci.*, 2000, 65, 1270–1282. <https://doi.org/10.1111/j.1365-2621.2000.tb10596.x>.
- [5] N. Chougui, N. Djerroud, F. Naraoui, S. Hadjal, K. Aliane, B. Zeroual and R. Larbat, Physicochemical properties and storage stability of margarine containing *Opuntia ficus-indica* peel extract as antioxidant, *Food Chem.*, 2015, 173, 382–390. <https://doi.org/10.1016/j.foodchem.2014.10.025>.
- [6] T. A. El-Adawy and K. M. Taha, Characteristics and composition of watermelon, pumpkin, and paprika seed oils and flours, *J. Agric. Food Chem.*, 2001, 49, 1253–1259. <https://doi.org/10.1021/jf001117+>.
- [7] L. Himed and M. Barkat, Élaboration d’une nouvelle margarine additionnée des huiles essentielles de Citrus limon, *OCL*, 2014, 21, A102. <https://doi.org/10.1051/ocl/2013050>.
- [8] G. Kaanin-Boudraa, F. Brahmi, M. Wrona, C. Nerín and L. Boulekbache-Makhlouf, Citrus × paradisi essential oil as a promising agent for margarine storage stability: composition and antioxidant capacity, *J. Food Process. Preserv.*, 2021, 45, e15374. <https://doi.org/10.1111/jfpp.15374>.
- [9] C. de Oliveira Lopes, M. de Fátima Pêcolo Barcelos, N. A. Araujo Dias, J. de Deus Souza Carneiro and W. C. de Abreu, Effect of the addition of spices on reducing the sodium content and increasing the antioxidant activity of margarine,

- LWT–Food Sci. Technol., 2014, 58, 63–70. <https://doi.org/10.1016/j.lwt.2014.02.029>.
- [10] A. Avetisyan, A. Markosian, M. Petrosyan, N. Sahakyan, A. Babayan, S. Aloyan and A. Trchounian, Chemical composition and some biological activities of the essential oils from basil *Ocimum* different cultivars, *BMC Complement. Altern. Med.*, 2017, 17, 60. <https://doi.org/10.1186/s12906-017-1587-5>.
- [11] A. I. Hussain, F. Anwar, S. T. H. Sherazi and R. Przybylski, Chemical composition, antioxidant and antimicrobial activities of basil (*Ocimum basilicum*) essential oils depends on seasonal variations, *Food Chem.*, 2008, 108, 986–995. <https://doi.org/10.1016/j.foodchem.2007.12.010>.
- [12] I. Telci, E. Bayram, G. Yılmaz and B. Avci, Variability in essential oil composition of Turkish basil (*Ocimum basilicum* L.), *Biochem. Syst. Ecol.*, 2006, 34, 489–497. <https://doi.org/10.1016/j.bse.2006.01.009>.
- [13] S.-J. Lee, K. Umamo, T. Shibamoto and K.-G. Lee, Identification of volatile components in basil and thyme leaves and their antioxidant properties, *Food Chem.*, 2005, 91, 131–137. <https://doi.org/10.1016/j.foodchem.2004.05.056>.
- [14] R. Amorati, M. C. Foti and L. Valgimigli, Antioxidant activity of essential oils, *J. Agric. Food Chem.*, 2013, 61, 10835–10847. <https://doi.org/10.1021/jf403496k>.
- [15] International Organization for Standardization, Animal and vegetable fats and oils—Determination of peroxide value—Iodometric (visual) endpoint determination, ISO 3960:2017, Geneva, 2017.
- [16] International Organization for Standardization, Animal and vegetable fats and oils—Determination of acid value and acidity, ISO 660:2020, Geneva, 2020.
- [17] Codex Alimentarius Commission, Standard for Edible Fats and Oils Not Covered by Individual Standards, CXS 19-1981, amended 2024.
- [18] R. P. Adams, Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry, 4th ed., Allured Publishing, Carol Stream, IL, 2007.
- [19] National Institute of Standards and Technology, NIST/EPA/NIH Mass Spectral Library, NIST 08, Gaithersburg, MD, 2008.
- [20] W. A. König, D. H. Hochmuth and D. Joulain, Terpenoids and Related Constituents of Essential Oils, MassFinder 2.1, Hamburg, 2001.
- [21] H. van den Dool and P. D. Kratz, A generalization of the retention index system including linear temperature programmed gas–liquid partition chromatography, *J. Chromatogr.*, 1963, 11, 463–471. [https://doi.org/10.1016/S0021-9673\(01\)80947-X](https://doi.org/10.1016/S0021-9673(01)80947-X).
- [22] C. Bicchì, P. Rubiolo, C. Cordero, F. Liberto, B. Sgorbini and P. Sandra, Dual secondary-ion mass-spectrometric and retention-index identification of essential-oil components, *Flavour Fragr. J.*, 2008, 23, 382–391. <https://doi.org/10.1002/ffj.1905>.
- [23] A. A. Wani, D. S. Sogi, P. Singh and A. Götz, Impacts of refining and antioxidants on the physico-chemical characteristics and oxidative stability of watermelon seed oil, *J. Am. Oil Chem. Soc.*, 2013, 90, 1423–1430. <https://doi.org/10.1007/s11746-013-2277-1>.
- [24] S. M. Abdulkarim, K. Long, O. M. Lai, S. K. S. Muhammad and H. M. Ghazali, Some physico-chemical properties of *Moringa oleifera* seed oil extracted using solvent and aqueous enzymatic methods, *Food Chem.*, 2005, 93, 253–263. <https://doi.org/10.1016/j.foodchem.2004.09.023>.
- [25] J. Yamoneka, P. Malumba, C. Blecker, M. Gindo, G. Richard, M.-L. Fauconnier, G. Lognay and S. Danthine, Physicochemical properties and thermal behaviour of African wild mango (*Irvingia gabonensis*) seed fat, *LWT–Food Sci. Technol.*, 2015, 64, 989–996. <https://doi.org/10.1016/j.lwt.2015.06.035>.
- [26] T. Waraho, D. J. McClements and E. A. Decker, Mechanisms of lipid oxidation in food dispersions, *Trends Food Sci. Technol.*, 2011, 22, 3–13. <https://doi.org/10.1016/j.tifs.2010.11.003>.
- [27] T. Waraho, V. Cardenia, M. T. Rodriguez-Estrada, D. J. McClements and E. A. Decker, Prooxidant mechanisms of free fatty acids in stripped soybean oil-in-water emulsions, *Food Chem.*, 2011, 129, 854–859. <https://doi.org/10.1016/j.foodchem.2011.05.034>.
- [28] European Medicines Agency, Public statement on the use of herbal medicinal products containing estragole, Revision 1, EMA/HMPC/137212/2005 Rev. 1, Amsterdam, 2023.
- [29] European Commission, Scientific Committee on Food, Opinion of the Scientific Committee on Food on Estragole, SCF/CS/FLAV/FLAVOUR/6 ADD2 Final, Brussels, 2001.
- [30] T. Silou, Corps gras non conventionnels du bassin du Congo: caractéristiques et valorisation, OCL, 2014, 21, D209. <https://doi.org/10.1051/ocl/2013044>.