LEBDA MEDICAL JOURNAL, VOL. 11, NO. 2 (30 October 2026), PP. 18–26.

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

Phenological Variation in Essential-Oil Yield and In Vitro Antibacterial Activity of *Thymus algeriensis* and *Thymus capitatus* from Tarhuna, Libya

Abdulaziz Suwaydan[a,b,&*], Ismail Ajaj[c], Mohamed A. S. Fahej[d],

[a] Department of Biology, Faculty of Science, Misurata University, Misurata, Libya

[b] Department of Pharmacognosy, Faculty of Pharmacy, Elmergib University, Al-Khums, Libya

[c] Department of Chemistry, Faculty of Education, Alasmarya University, Zliten, Libya

[d] Libyan Academy for Postgraduate Studies, Al-Khums Branch, Al-Khums, Libya

*Corresponding author Email: asswedan@elmergib.edu.ly

A B S T R A C T

Background: Phenological development can strongly influence essential-oil (EO) production in aromatic plants, although comparative evidence for Libyan Thymus species remains limited.

Aims: To quantify phenological variation in EO yield of *Thymus algeriensis* and *Thymus capitatus* from Tarhuna, Libya, and to describe the in vitro antibacterial activity of the corresponding pooled oils.

Methods: Dried aerial parts collected at vegetative, flowering and post-flowering stages were hydrodistilled for 3 h using a Clevenger apparatus. Three independent hydrodistillations were performed per species × stage combination. Yield was analysed by two-way factorial ANOVA. The three oils from each combination were then pooled and screened by disc diffusion against *Staphylococcus aureus* ATCC 25923 and *Escherichia coli* ATCC 25922 using three technical disc measurements.

Results: Yield was affected by species, stage and their interaction (all $p < 0.0001$). Flowering produced the highest yield in both species: 1.85 ± 0.05% in *T. algeriensis* and 3.22 ± 0.10% in *T. capitatus*. The species × stage interaction was very large (partial $\eta^2 = 0.942$), reflecting a modest flowering increase in *T. algeriensis* (+13.3% over vegetative) versus a much larger increase in *T. capitatus* (+62.2%). Mean inhibition zones of pooled oils ranged from 22.67 to 25.33 mm; the largest observed zone was obtained against *E. coli* with post-flowering *T. capitatus* oil.

Conclusion: Phenological timing has species-specific consequences for EO recovery, with flowering providing the highest yield under the investigated conditions. Antibacterial patterns did not parallel the yield trajectory. Because oils were pooled before antibacterial testing, activity differences are descriptive and require confirmation using independently tested extraction replicates and quantitative dilution assays.

Keywords: antibacterial activity; essential oil; phenology; Thymus algeriensis; Thymus capitatus

LEBDA MEDICAL JOURNAL, VOL. 11, NO. 2 (30 October 2026), PP. 18–26.

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

1. Introduction

Medicinal and aromatic plants of the Lamiaceae are important sources of essential oils (EOs) used in traditional medicine, food preservation, cosmetics, and fragrance-related applications. Essential-oil production is not a fixed taxonomic characteristic; both oil yield and composition are influenced by genotype, developmental stage, environmental conditions, harvest timing, post-harvest handling, and extraction procedure [1,2]. Phenological stage is therefore an important determinant of EO productivity because developmental changes in vegetative growth, reproductive allocation, glandular structures, and secondary-metabolite biosynthesis can modify both the amount and chemical profile of volatile constituents. Although maximum EO accumulation is frequently reported near flowering in aromatic Lamiaceae, the magnitude and even direction of the response may vary among species and populations [1,2].

T. algeriensis Boiss. & Reut. is a North African thyme characterized by substantial geographic and chemical variability. Population-level differences in EO yield and composition have been documented, indicating that geographic origin and local environmental conditions contribute importantly to its volatile phenotype [3]. Sampling period may further modify extraction yield, chemical composition, and associated biological activity [4,5]. Consequently, phenological responses observed in one population cannot necessarily be extrapolated to another, particularly in environmentally heterogeneous Mediterranean habitats.

T. capitatus is similarly characterized by pronounced temporal and geographic variation. Studies of Mediterranean populations have reported increases in EO accumulation toward flowering followed by decreases during later developmental stages, together with substantial changes in volatile composition [6,7]. Geographic comparisons likewise demonstrate marked differences among populations in both EO yield and constituent profiles [8,9]. Collectively, these findings indicate that harvest stage and population origin are important determinants of the quantitative and qualitative EO phenotype of *Thymus* species.

Recent Libyan investigations provide particularly relevant evidence of this heterogeneity. Essential oil of *T. algeriensis* collected from Gaser Alhaj was characterized by GC-MS as a strongly carvacrol-dominant profile, with carvacrol accounting for 77.01% of the identified oil and with γ-terpinene, thymol, and cymene derivatives among the accompanying constituents; the oil also showed antibacterial activity against *E. coli* [10]. Similarly, *T. capitatus* collected from Mesellata exhibited a carvacrol-rich profile dominated by carvacrol (56.27%), followed by p-cymene (9.51%), γ-terpinene (8.39%), and thymol (6.54%) [11]. The Mesellata study also placed this profile within the wider chemical variability reported among Libyan populations and discussed harvest stage and local ecological conditions as possible contributors to the observed differences [11]. These national data reinforce the need to interpret Libyan *Thymus* populations within their specific geographic and developmental contexts rather than assuming a uniform chemical phenotype.

The broader Libyan EO literature likewise demonstrates considerable phytochemical and biological diversity. *Artemisia herba-alba* from Zintan produced a camphor-thujone-dominant EO with antibacterial activity against methicillin-resistant *Staphylococcus aureus* [12], whereas *A. judaica* collected from Al-Awaynat inhibited both *S. aureus* and *E. coli*, with different responses between direct-contact disc diffusion and vapour-phase testing [13]. In the Green Mountain region, *Satureja thymbra* EO was reported to contain thymol as its predominant identified constituent and exhibited antibacterial activity against *S. aureus* and *E. coli* [14]. More recently, *Eucalyptus camaldulensis* from northwestern Libya showed a chemically distinct 1,8-cineole/α-pinene-dominant profile together with strain-dependent antibacterial activity, with the greatest inhibition observed against *S. aureus* [15]. Taken together, these studies demonstrate an expanding national evidence base for chemically diverse, biologically active Libyan EOs, while also illustrating that antibacterial responses depend on botanical source, chemical profile, bacterial strain, and experimental methodology.

Corresponding author, email: asswedan@elmergib.edu.ly

LEBDA MEDICAL JOURNAL, VOL. 11, NO. 2 (30 October 2026), PP. 18–26.

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

Against this national background, both *T. algeriensis* and *T. capitatus* have documented antimicrobial potential. Comparative investigations have demonstrated activity of their EOs against food-associated and reference microorganisms, including *S. aureus* and *E. coli* [16]. Chemically characterized Libyan *T. capitatus* oil has likewise shown antimicrobial activity [17], while additional studies support antibacterial and antibiofilm effects for these species [18,19]. Nevertheless, EO yield and antibacterial activity represent related but distinct biological attributes. Total EO yield reflects the quantity of recovered volatile material, whereas antimicrobial activity depends on constituent identity and relative abundance, interactions among components, organism susceptibility, EO concentration, and assay conditions [20]. Accordingly, greater oil production should not be assumed to correspond automatically to greater antibacterial activity.

Despite the expanding national and international literature, comparative information remains limited on how phenological stage influences EO yield in *T. algeriensis* and *T. capitatus* growing at the same Libyan locality under a common sampling and extraction framework, and whether the antibacterial screening patterns of the corresponding oils follow the same developmental trajectory. Addressing this gap requires a same-locality comparison across defined developmental stages while distinguishing the inferential analysis of independently replicated EO-yield measurements from descriptive antibacterial screening when extraction oils are pooled before testing.

Aims

This study aimed to quantify the effects of species, phenological stage and their interaction on essential-oil yield under a standardized Tarhuna sampling and hydrodistillation framework, and to describe the antibacterial screening pattern of the corresponding pooled oils against *S. aureus* ATCC 25923 and *E. coli* ATCC 25922.

2. Methods

Study design and plant material

The study used a balanced comparative design including two Thymus species (*T. algeriensis* and *T. capitatus*) across three phenological stages: vegetative (V), flowering (F) and post-flowering (PF). Aerial parts were collected from wild growing plants in Tarhuna, Libya, during 2025. Plant material was dried before extraction. Botanical identity was authenticated at the National Herbarium, Department of Botany, Faculty of Science, University of Tripoli, Libya, by Prof. Mohammed Makhlouf.

EO extraction and yield determination

For each separate extraction, 100 g of dried aerial plant material was subjected to hydrodistillation using a Clevenger-type apparatus for 3 h. These separate hydrodistillation runs were conducted for every species × phenological-stage combination, resulting in 18 independent yield measurements. EO yield was expressed as percentage volume per dry mass (% v/w, on dry-weight basis). The three independent yield values were kept separately for subsequent statistical analysis. Following yield measurements, the three oils obtained from each species × stage combination were combined to produce a single pooled EO preparation for antibacterial screening.

Bacterial strains and disc-diffusion assay

Antibacterial activity was assessed using American Type Culture Collection (ATCC) reference strains *S. aureus* ATCC 25923 and *E. coli* ATCC 25922. Mueller-Hinton agar served as the nutrient test medium and bacterial inoculum was standardized to 0.5 McFarland. Sterile 6-mm paper discs were impregnated with 1 µL of the respective pooled EO. Each pooled oil was tested using three technical disc measurements against each bacterium. Plates were incubated at 35 °C for 18 h, and total inhibition-zone diameter, including the 6-mm disc, was recorded in millimetres. The disc-diffusion assay is suitable for antibacterial screening, but zone diameter is influenced by compound

Corresponding author, email: asswedan@elmergib.edu.ly

LEBDA MEDICAL JOURNAL, VOL. 11, NO. 2 (30 October 2026), PP. 18–26.

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

diffusion through the agar matrix and should not be interpreted as a direct quantitative measure of intrinsic antimicrobial potency [21]. Gentamicin (10 µg/disc) served as the positive-control reference and produced a reported 20-mm inhibition zone for both bacterial strains. The negative control (sterile disc) produced no inhibition (0 mm).

Statistical analysis

Each hydrodistillation run was considered an independent unit for analysis of EO yield (n = 3 per species × stage). Yield data were expressed as mean ± standard deviation (SD), coefficient of variation (CV), range and 95% confidence interval. Species, phenological stage and their interaction were tested with a two-way factorial linear model with Type III tests. Model assumptions were assessed using residual plots, Shapiro-Wilk, Brown-Forsythe and Levene tests, while partial eta squared (ηp^2) was used for effect size. Estimated marginal means and Tukey-adjusted pairwise comparisons were applied to compare groups. Antibacterial data were summarized descriptively as mean ± technical SD, range and CV. Analyses were performed in R 4.6.0.

3. Results

Phenological variation in essential-oil yield

EO yield differed markedly between species and across developmental stages (Table 1; Figure 1). In *T. algeriensis*, yield increased from 1.63 ± 0.06% at the vegetative stage to 1.85 ± 0.05% at flowering and then declined to 1.23 ± 0.03% post-flowering. In *T. capitatus*, corresponding values were 1.98 ± 0.08%, 3.22 ± 0.10% and 2.18 ± 0.03%. Flowering therefore represented the maximum-yield stage in both species, but the amplitude of the flowering response was much greater in *T. capitatus*.

Table 1. Essential-oil yield of *T. algeriensis* and *T. capitatus* across phenological stages.

Species	Phenological stage	n	EO yield (% v/w, DW), mean ± SD	CV (%)	Tukey group
T. algeriensis	Vegetative	3	1.63 ± 0.06	3.53	a
T. algeriensis	Flowering	3	1.85 ± 0.05	2.70	b
T. algeriensis	Post-flowering	3	1.23 ± 0.03	2.34	d
T. capitatus	Vegetative	3	1.98 ± 0.08	3.85	b
T. capitatus	Flowering	3	3.22 ± 0.10	3.24	c
T. capitatus	Post-flowering	3	2.18 ± 0.03	1.32	e

Note:Values are based on three independent hydrodistillations. Different lowercase letters indicate significant differences among the six species × stage combinations in the Tukey-adjusted all-cell comparison ($p < 0.05$); means sharing a letter are not significantly different.

Factorial-model assumptions were satisfactory. Residuals did not deviate significantly from normality (Shapiro-Wilk W = 0.954, p = 0.495), and neither the Brown-Forsythe test ($F_{5,12} = 0.482$, p = 0.783) nor the mean-centred Levene test ($F_{5,12} = 1.923$, p = 0.164) indicated significant variance heterogeneity. The model explained 99.29% of observed yield variation ($R^2 = 0.9929$; adjusted $R^2 = 0.9900$).

Two-way analysis of variance (ANOVA) showed highly significant effects of species ($F_{1,12} = 882.76$, $p = 1.32 \times 10^{-12}$), phenological stage ($F_{2,12} = 301.97$, $p = 5.47 \times 10^{-11}$) and species × stage interaction ($F_{2,12} = 97.28$, $p = 3.85 \times 10^{-8}$) (Table 2). Partial ηp^2 values were 0.987, 0.981 and 0.942, respectively, indicating large effects and phenological response differed substantially between the two species.

Table 2. Two-way factorial analysis of variance for EO yield.

Source	Sum of squares	df	F	p	Partial ηp^2
Species	3.556	1	882.76	1.32×10^{-12}	0.987
Phenological stage	2.433	2	301.97	5.47×10^{-11}	0.981
Species × Stage	0.784	2	97.28	3.85×10^{-8}	0.942
Residual	0.048	12	—	—	—

Partial ηp^2 values were calculated from the Type III factorial model.

Corresponding author, email: asswedan@elmergib.edu.ly

LEBDA MEDICAL JOURNAL, VOL. 11, NO. 2 (30 October 2026), PP. 18–26.

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

Within *T. algeriensis*, flowering yield exceeded vegetative yield by 0.217 percentage points ($p = 0.0034$) and post-flowering yield by 0.617 percentage points ($p < 0.0001$); vegetative yield also exceeded post-flowering yield (difference = 0.400 percentage points, $p < 0.0001$). Within *T. capitatus*, flowering exceeded both vegetative (difference = 1.233 percentage points, $p < 0.0001$) and post-flowering stages (difference = 1.033 percentage points, $p < 0.0001$), while post-flowering also exceeded vegetative yield (difference = 0.200 percentage points, $p = 0.0059$).

Relative to the vegetative stage, flowering increased EO yield by 13.3% in *T. algeriensis* and 62.2% in *T. capitatus*. Yield declined from flowering to post-flowering by 33.3% and 32.1%, respectively. Across matched stages, *T. capitatus* produced 21.4% more oil than *T. algeriensis* during vegetative growth, 73.9% more at flowering and 77.0% more post-flowering; these between-species contrasts were significant at every stage (all $p < 0.0001$ in stage-specific species comparisons). The only nonsignificant pair in the six-cell Tukey family was vegetative *T. capitatus* versus flowering *T. algeriensis* ($p = 0.1778$).

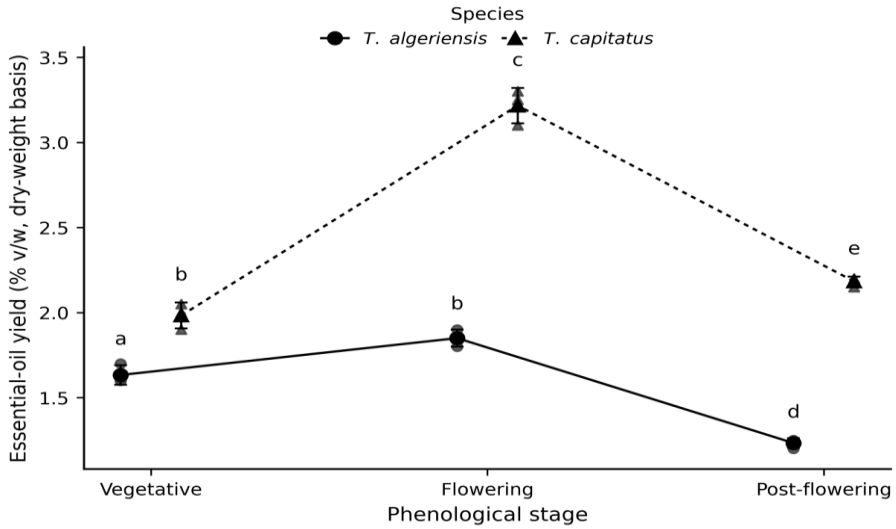


Figure 1. Phenological variation in essential-oil yield of *T. algeriensis* and *T. capitatus*. Individual symbols represent independent hydrodistillation runs (n = 3 per species × stage combination); central symbols and error bars represent mean ± SD. Different lowercase letters indicate significant differences among the six species × stage means after Tukey adjustment ($p < 0.05$).

Descriptive antibacterial activity of pooled oils

All pooled EO preparations produced measurable inhibition against both test strains, with mean zones ranging from 22.67 to 25.33 mm (Table 3; Fig. 2). Against *S. aureus*, mean zones for *T. algeriensis* were 24.67 ± 0.58, 24.33 ± 0.58 and 23.33 ± 0.58 mm at vegetative, flowering and post-flowering stages, respectively; corresponding values for *T. capitatus* were 24.67 ± 0.58, 23.67 ± 0.58 and 23.33 ± 0.58 mm. The observed *S. aureus* pattern showed a modest decline toward post-flowering in both species.

Against *E. coli*, *T. algeriensis* produced mean zones of 22.67 ± 0.58, 24.67 ± 0.58 and 24.67 ± 0.58 mm, whereas *T. capitatus* produced 24.67 ± 0.58, 24.67 ± 0.58 and 25.33 ± 0.58 mm. The largest observed inhibition zone in the dataset occurred with post-flowering *T. capitatus* oil against *E. coli*. The mean technical CV across the 12 pooled-oil × strain combinations were 2.39%, indicating low dispersion among technical disc measurements.

Corresponding author, email: asswedan@elmergib.edu.ly

LEBDA MEDICAL JOURNAL, VOL. 11, NO. 2 (30 October 2026), PP. 18–26.

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

Table 3. Descriptive antibacterial activity of pooled essential oils across phenological stages.

Species/treatment	Stage	*S. aureus* ATCC 25923, zone (mm)	*E. coli* ATCC 25922, zone (mm)
T. algeriensis	V	24.67 ± 0.58 (24–25)	22.67 ± 0.58 (22–23)
T. algeriensis	F	24.33 ± 0.58 (24–25)	24.67 ± 0.58 (24–25)
T. algeriensis	PF	23.33 ± 0.58 (23–24)	24.67 ± 0.58 (24–25)
T. capitatus	V	24.67 ± 0.58 (24–25)	24.67 ± 0.58 (24–25)
T. capitatus	F	23.67 ± 0.58 (23–24)	24.67 ± 0.58 (24–25)
T. capitatus	PF	23.33 ± 0.58 (23–24)	25.33 ± 0.58 (25–26)
Gentamicin, 10 µg/disc	—	20	20
Negative control	—	0	0

Essential-oil values are mean ± technical SD with observed range in parentheses. The three independent extraction oils within each species × stage group were pooled before antibacterial testing; biological n = 1 per pooled preparation, and no inferential species- or stage-level tests were performed. Control values were single reported measurements.

All pooled oils produced mean zones numerically above the 20-mm gentamicin reference response. These numerical differences were not tested statistically and should not be interpreted as evidence that the EOs were more potent than gentamicin, because dose, physicochemical diffusion properties and replication structure were not equivalent between treatments.

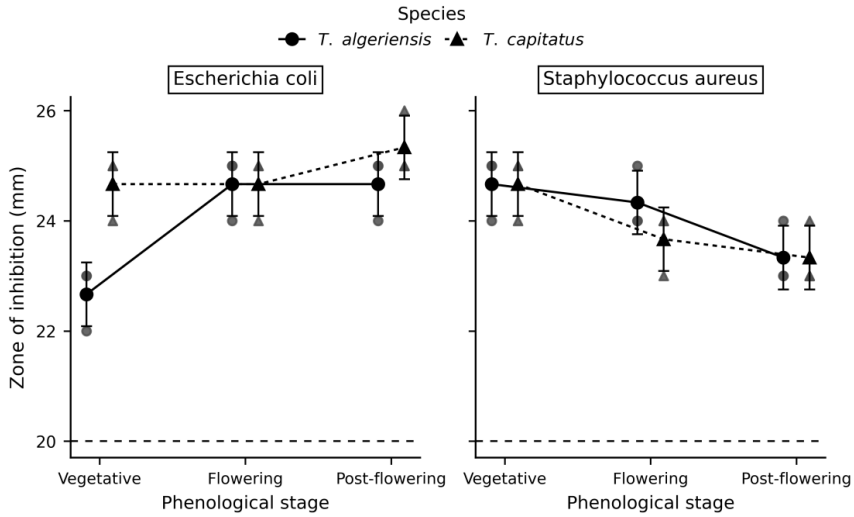


Figure 2. Descriptive antibacterial screening of pooled essential oils against *E. coli* ATCC 25922 and *S. aureus* ATCC 25923. Points are technical disc measurements and error bars are technical SD. The horizontal dashed line denotes the reported gentamicin 10 µg/disc reference response (20 mm). No inferential testing was performed for antibacterial activity because independent extraction oils were pooled before disc testing.

4. Discussion

EO yield was strongly influenced by phenological stage, but the magnitude of this response differed between the two species. Flowering produced the highest yield in both taxa, although the increase from vegetative to flowering was modest in *T. algeriensis* (+13.3%) and much greater in *T. capitatus* (+62.2%). The large species × stage interaction (partial $\eta p^2 = 0.942$) therefore shows that phenological development affects the two species differently.

The mechanisms responsible for this interaction were not measured directly. However, developmental changes in glandular tissues,

Corresponding author, email: asswedan@elmergib.edu.ly

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

secretory-trichome density, biomass allocation and monoterpene biosynthesis may contribute to stage-dependent variation, while environmental factors such as temperature, light and water status may further modify EO production [2]. The *T. capitatus* pattern agrees with previous reports of increasing EO yield toward flowering followed by post-flowering decline [6,7]. In *T. algeriensis*, the response was less pronounced and published evidence is more variable, with phenological effects differing among populations and locations [3,5].

T. capitatus produced more EO than *T. algeriensis* at all stages, with the difference increasing from 21.4% during vegetative growth to 73.9% at flowering and 77.0% post-flowering. Thus, harvest timing appears particularly important for *T. capitatus* when the aim is to maximize EO recovery. Flowering was the most productive stage for both species under the conditions studied. However, this conclusion applies to EO quantity only. Previous studies show that EO composition can also change markedly during development [1,6,7]. Because chemical profiling was not performed here, flowering should be considered the optimum stage for yield rather than necessarily for chemical quality.

Geographic variation is common in Thymus species, with differences in EO yield and composition reported among populations [3,8,9]. Therefore, the flowering maximum observed here should be interpreted as a local optimum for the Tarhuna populations studied in 2025 rather than a universal value.

All pooled oils inhibited *S. aureus* and *E. coli*, consistent with previous reports on these species [16–19]. However, antibacterial activity did not follow the same pattern as EO yield. Flowering *T. capitatus* produced the highest EO yield, whereas the largest inhibition zone occurred with post-flowering *T. capitatus* against *E. coli*. Similarly, *T. algeriensis* had its highest yield at flowering, but its largest *S. aureus* inhibition zone occurred at the vegetative stage.

This divergence is biologically plausible because EO yield represents total volatile quantity, whereas antibacterial activity depends on the composition, relative abundance and interactions of individual constituents. Carvacrol and thymol are important constituents of many *T. capitatus* oils [8,9,11,17]. More recently, GC-MS analysis of Libyan *T. capitatus* collected from Mesellata identified a carvacrol-rich profile dominated by carvacrol (56.27%), with p-cymene, γ-terpinene and thymol among the other prominent constituents [11]. However, chemical profiling was not performed on the Tarhuna oils investigated here; therefore, the Mesellata composition cannot be assumed for the present samples, and the observed antibacterial patterns cannot be attributed to specific constituents. The results also do not support a simple Gram-positive versus Gram-negative susceptibility pattern, because *S. aureus* inhibition tended to decrease after flowering, whereas *E. coli* responses were maintained or increased [20,22].

5. Conclusion

Phenological stage exerted a major, species-dependent effect on EO yield of *T. algeriensis* and *T. capitatus* from Tarhuna, Libya. Flowering produced the highest yield for both species, with a particularly large increase in *T. capitatus*, whose yield increased by 62.2% relative to the vegetative stage. The significant species × stage interaction shows that the effect of harvest stage differs between the two species. All pooled oils produced measurable inhibition of *S. aureus* ATCC 25923 and *E. coli* ATCC 25922 in disc-diffusion screening, but the descriptive antibacterial patterns did not mirror the yield trajectory. Because independently extracted oils were pooled before antibacterial testing, these activity differences are descriptive rather than inferential. The study identifies flowering as the optimal stage for maximizing EO recovery under the conditions studied, while highlighting the need for follow-up chemically characterized, biologically replicated minimum inhibitory concentration/minimum bactericidal concentration studies before mechanistic or potency conclusions can be drawn.

Corresponding author, email: asswedan@elmergib.edu.ly

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

ABBREVIATIONS AND ACRONYMS

EO, essential oil; V, vegetative; F, flowering; PF, post-flowering; SD, standard deviation; CV, coefficient of variation; ANOVA, analysis of variance; ATCC, American Type Culture Collection; MIC, minimum inhibitory concentration; MBC, minimum bactericidal concentration.

ETHICAL STATEMENT:

This study involved plant material and established bacterial reference strains and did not involve human participants or experimental animals. Ethical approval was therefore not applicable.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to this work.

AUTHORS' CONTRIBUTIONS

A.S.: Conceptualization, methodology, investigation, data curation, statistical analysis, visualization, and writing original draft.
I.A.: Methodology, supervision, validation, and writing—review and editing.
M.S.: Supervision, validation, and writing—review and editing.
All authors read and approved the final manuscript.

6. References

1. Stefanakis MK, et al. Seasonal variation of aromatic plants under cultivation conditions. Plants (Basel). 2022;11(16):2083. Available from: https://doi.org/10.3390/plants11162083

2. Mansinhos I, Gonçalves S, Romano A. How climate change-related abiotic factors affect the production of industrial valuable compounds in Lamiaceae plant species: a review. Front Plant Sci. 2024;15:1370810. Available from: https://doi.org/10.3389/fpls.2024.1370810

3. Zouari N, et al. Variation of chemical composition of essential oils in wild populations of Thymus algeriensis Boiss. et Reut., a North African endemic species. Lipids Health Dis. 2012;11:28. Available from: https://doi.org/10.1186/1476-511X-11-28

4. Ouakouak H, et al. Biological properties of essential oils from Thymus algeriensis Boiss. Plants (Basel). 2021;10(4):786. Available from: https://doi.org/10.3390/plants10040786

5. Souiy Z, et al. Optimization of extraction yield, chemical composition, antioxidant, and antimicrobial activities of Thymus algeriensis Boiss. & Reut essential oils. Biocatal Agric Biotechnol. 2023;47:102593. Available from: https://doi.org/10.1016/j.bcab.2022.102593

6. Hedhili L, et al. Variability in essential oil composition of Tunisian Thymus capitatus (L.) Hoffmanns. et Link. Flavour Fragr J. 2002;17(1):26-28. Available from: https://doi.org/10.1002/ffj.1029

7. Tan U. Ontogenetic regulation of metabolite dynamics in Thymbra capitata: temporal reconfiguration of essential oils and antioxidant capacities across sequential harvests. PeerJ. 2026;14:e21519. Available from: https://doi.org/10.7717/peerj.21519

8. Tagnaout I, et al. Chemical composition, antioxidant and antibacterial activities of Thymus broussonetii Boiss and Thymus capitatus (L.) Hoffmann and Link essential oils. Plants (Basel). 2022;11(7):954. Available from: https://doi.org/10.3390/plants11070954

9. Jaradat N, et al. Variations of the chemical components and biological activities of Thymus capitatus essential oil from three regions in Palestine. Sci Rep. 2025;15(1):16305. Available from: https://doi.org/10.1038/s41598-025-92835-7

10. Giweli AA, Alzentani OT, Kammon AM. Chemical composition and bioactivity of a carvacrol-rich Thymus algeriensis essential oil from Gaser Alhaj, Libya. Libyan Journal of Medical and Applied Sciences. 2025;3(3):138-143. Available from: https://doi.org/10.64943/ljmas.v3i3.164

11. Suwaydan AS, Altraiki MS. GC-MS analysis of essential oil components of the Libyan Thymus capitatus. Lebda Med J. 2025;10(1):1-11. Available from: https://doi.org/10.65137/lmj.v10i1.220

12. Giweli A, et al. Camphor-thujone chemotype and bioactivities of Artemisia herba-alba Asso essential oil from Zintan, Libya: chemical composition, antibacterial, and antiproliferative effects. Alqalam Journal of Medical and Applied Sciences. 2025;8(4):2578-2585. Available from: https://doi.org/10.54361/ajmas.258468

Corresponding author, email: asswedan@elmergib.edu.ly

Lebda Medical Journal; [LMJ]; {Online ISSN:2520-095X}

Lebda Medical Journal Homepage: https://lebmedj.elmergib.edu.ly/index.php/LMJ/en

Received:30.9.2026; Revised:11.10.2026; Accepted:14.10.2026: Published:30.10.2026

13. Tamer AR, Suwaydan AS, Ghalbun A. Comparative evaluation of disc diffusion and volatilization methods for assessing the antibacterial activity of essential oil of Libyan Artemisia judaica against pathogenic bacteria. Lebda Med J. 2025;10(2):35-40. Available from: https://doi.org/10.65137/lmj.v10i2.263

14. El-jalel LFA, et al. Efficacy of mountain thyme oil against S. aureus and E. coli: a study on antibacterial resistance. Afro-Asian Journal of Scientific Research. 2025;3(3):32-38. No accessible link or DOI was found in the search results.

15. Zughdani M, et al. Chemical composition and in vitro antioxidant and antibacterial activities of Eucalyptus camaldulensis leaf essential oil from northwestern Libya. African Journal of Advanced Pure and Applied Sciences. 2026;5(3):552-560.

16. Jayari A, et al. Essential oils from Thymus capitatus and Thymus algeriensis as antimicrobial agents to control pathogenic and spoilage bacteria in ground meat. J Food Qual. 2021;2021:5599374. Available from: https://doi.org/10.1155/2021/5599374

17. Džamić AM, et al. Libyan Thymus capitatus essential oil: antioxidant, antimicrobial, cytotoxic and colon pathogen adhesion-inhibition properties. J Appl Microbiol. 2015;119(2):389-399. Available from: https://doi.org/10.1111/jam.12864

18. Almeida L, et al. Thymbra capitata essential oil has a significant antimicrobial activity against methicillin-resistant Staphylococcus aureus pre-formed biofilms. Lett Appl Microbiol. 2022;74(5):787-795. Available from: https://doi.org/10.1111/lam.13665

19. Ben Selma W, et al. Thymus algeriensis essential oil: phytochemical investigation, bactericidal activity, synergistic effect with colistin, molecular docking, and dynamics analysis against Gram-negative bacteria resistant to colistin. Heliyon. 2024;10(19):e38281. Available from: https://doi.org/10.1016/j.heliyon.2024.e38281

20. Angane M, et al. Essential oils and their major components: an updated review on antimicrobial activities, mechanism of action and their potential application in the food industry. Foods. 2022;11(3):464. Available from: https://doi.org/10.3390/foods11030464

21. Balouiri M, Sadiki M, Ibnsouda SK. Methods for in vitro evaluating antimicrobial activity: a review. J Pharm Anal. 2016;6(2):71-79. Available from: https://doi.org/10.1016/j.jpha.2015.11.005

22. Hulankova R. Methods for determination of antimicrobial activity of essential oils in vitro—a review. Plants (Basel). 2024;13(19):2784. Available from: https://doi.org/10.3390/plants13192784

Corresponding author, email: asswedan@elmergib.edu.ly