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Saline soil adaptations of Kratai Cham (*Adenosma indianum* (Lour.) Merr.): A comprehensive study on life cycle, leaf epidermis, and FTIR analysis of essential oils

Woraporn Laojinda[1], Piyanut Khanema[1*]

[1] *Department of Biology, Faculty of Science, Mahasarakham University, Maha Sarakham, 44150, Thailand*

[*] *Corresponding author: piyanoot_kh@hotmail.com*

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Abstract - Kratai Cham (*Adenosma indianum* (Lour.) Merr.), similar to the camphor tree, produces fragrant essential oils rich in limonene found in glandular trichomes. These oils are renowned for their antibacterial, anti-inflammatory, and therapeutic properties in traditional medicine, particularly for neurodegenerative disorders. Recently, Kratai Cham has thrived in saline soils, prompting our investigation in Kalasin Province, Thailand, from 2019 to 2022. This research aimed to evaluate the influence of salinity on Kratai Cham, with particular relevance to its essential oils. The observation revealed that the life cycle of Kratai Cham spanned from July to February, and this cycle correlated with soil salinity, which ranged from 13.10 to 34.70 mmol Na/kg and 3.33 to 25.33 mmol Cl/kg. Salinity led to reduced stomatal size but increased numbers and indices of stomata and trichomes, notably the two glandular trichomes, capitate and peltate, on the lower epidermis. FTIR analysis revealed rising essential oil concentrations, particularly *d*-limonene, in response to salinity. Kratai Cham's saline adaptations offer medical promise, underscoring the significance of this research for unlocking its potential.

Keywords: Stomata, trichome, saline, epidermis, limonene

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1. Introduction

Kratai Cham (*Adenosma indianum* (Lour.) Merr.) is a plant highly regarded in traditional medicine throughout Thailand, China, and Vietnam, with potential applications across diverse domains. Belonging to the *Adenosma* genus, Kratai Cham was characterized by its distinctive aroma due to essential oils in various plant parts (Wang *et al*., 2021). This aromatic quality had earned it the alternative name "wild camphor." Notably, these essential oils shared compositional similarities with the camphor tree (*Cinnamomum camphora* Linn. J. Presl), featuring compounds such as limonene, pinene, myrcene, and camphor (Bhandari *et al*., 2022; Bhuiyan *et al*., 2010). The glandular trichomes on the epidermal layer were the primary site of essential oil production. Beyond its aromatic profile, Kratai Cham exhibited remarkable antibacterial, anti-inflammatory, and neurodegenerative disorder properties, especially in the context of Alzheimer's disease and multiple sclerosis, and it also served as an effective insect repellent (Eddin *et al*., 2021; Lemmens & Bunyapraphatsara, 2003; Wang *et al*., 2021; World Health Organization. Regional Office for the Western Pacific, 1990).

A new comprehensive examination of Kratai Cham's growth in the saline soil regions of Yang Talat District, Kalasin Province, and Borabue District, Maha Sarakham Province in northeastern Thailand had been reported (Tokaew & Mokkamol, 2016; Yuwaniyama, 2003). These regions had encountered disturbances in their original ecosystems, potentially stemming from human activities. Notably, they were situated within the saline soil zones of northeastern Thailand, heavily influenced by the rock salt salinity from the Maha Sarakham Formation, characterized by interlacing rock salt and sedimentary rocks. In specific areas, rock salt layers infiltrated into salt domes, resulting in substantial salt deposits on the soil surface (Wongsomsak, 1986; Arunin & Pongwichian, 2015), significantly impacting salt-sensitive plant species. The elevated soil salinity diminished the soil's water potential, adversely affecting the water use efficiency of plants. Moreover, excessive sodium uptake could impair cellular structures and led to leaf chlorosis, thereby influencing overall plant growth (Nawaz *et al*., 2022). In response to the challenging salinity stress, plants thriving in saline soils must undergo adaptive processes such as reconfiguring leaf epidermal anatomy, which played a pivotal role in essential oil production, and adjustments in the plant's life cycle. These adaptations were anticipated to be present in Kratai Cham as well.

To provide essential biological insights and make a meaningful contribution to the field of medicine, this research analyzed the life cycle, leaf epidermal characteristics, and the organic compound composition in the essential oils of Kratai Cham grown in saline soil environments.

2. Materials and methods

2.1 Study site

The study area was in the saline soil regions of Hua Na Kham Subdistrict and Khlong Kham Subdistrict, Yang Talat District, Kalasin Province, Thailand. The sampling area was divided into two zones based on the severity of soil salinity problems, as classified by Wichaidit (1995): the

'Slight-saline region' (salt content < 1%) and the 'Medium-saline region' (salt content 1-10%). The coordinates for the sampling sites were 16°25'17.8"N 103°17'41.7"E and 16°25'17.1"N 103°17'42.1"E, respectively. The maximum and minimum temperatures recorded during the 2019-2022 study period were 39.75°C and 13.5°C, respectively, with an average rainfall of 1,192 mm (data from Thai Meteorological Department). The predominant soil texture in these areas were loamy sand, primarily composed of sand (78.49-83.58%), silt (12.51-17.59%), and clay (3.90-4.33%), in respective proportions (data not shown).

2.2 Soil collection and soil property analysis

Soil sampling occurred in wet and dry seasons in October 2021 and December 2021. Bulk density observation was acquired from Heuscher *et al*. (2005). Samples were collected randomly from the 0-15 cm depth using the composite sampling method. The soil samples were divided into two parts: (*i*) for moisture content measurement through the oven drying method and (*ii*) for analyzing various soil parameters by drying in a shaded area. Soil moisture analysis was performed using the gravimetric method (Wiriyakitnateekul & Kerdchana, 2016), pH and electrical conductivity of saturated soil extracts (ECe) levels were determined using a pH-EC meter, nitrogen content was assessed via the Walkley & Black (1947) method, and the quantities of sodium, potassium, calcium, and magnesium were measured using an Atomic Absorption Spectrophotometer by the guidelines provided by the Land Development Department (2010). Chloride content was quantified using Mohr's Method, following the reference from Suwanwong (2003).

2.3 Life cycle study

The life cycle study was conducted from 2019 to 2022 in both salinity regions, encompassing data collection and photography. Growth stage observations in the field were carried out 1-2 times per week during March to May and 2-4 times per week from June to February.

2.4 Plant collection

Plant samples were randomly collected in October 2021 during the flowering stage, with triplicates of the sampling size measuring 5x5 m for each salinity region. These samples were subsequently divided into four parts: (*i*) specimens were identified, (*ii*) herbarium specimens were prepared as Laojinda-01 to Laojinda-03 and stored at the Biological Laboratory Room (sc1-309/1) at MSU, (*iii*) some samples were soaked in 70% ethanol for the examination of leaf epidermis morphology and anatomy, and (*iv*) the remaining samples were dried and ground before being extracted for the FTIR analysis of the essential oils.

2.5 Leaf epidermal analysis

Leaf samples preserved in 70% ethanol were dissected and sequentially treated with 5% potassium hydroxide for 15-20 minutes and 5% sodium hypochlorite for an equivalent duration. After rinsing with distilled water, they were briefly submerged in 70% ethanol. Staining was done using a 1% safranin solution, followed by ethanol dehydration with increasing concentrations (70%, 95%, 100%) and a 1:1 ethanol-xylene mixture, each step lasting 10 minutes. Post-dehydration, the samples were incubated in xylene for 15 minutes, mounted using

DePeX (Paworn *et al*., 2012; Promsing *et al*., 2016), and observed through a ZEISS Primostar 3 microscope with image capture. The analysis concentrated on leaf epidermal tissue characteristics such as stomatal length, stomatal cells, epidermal cells, and indices of stomata and trichomes by Dilcher (1974) methods. Stomatal and trichomes indices were calculated as follows:

$$Stomatal\ index\ (\%) = \left(\frac{S}{S+E}\right)x100$$

$$Trichome\ index\ (\%) = \left(\frac{T}{T+E}\right)x100$$

where S = stomatal cell numbers per 1 mm^2, T = trichome cell numbers per 1 mm^2, E = epidermal cell numbers per 1 mm^2.

2.6 FTIR analysis

Essential oil extraction employed two methods: hexane maceration and steam distillation, using a plant-to-solvent ratio of 1:10 (w/v), methods supported by Hasibuan *et al*. (2021) and Zeng *et al*. (2013), respectively. The solvent mixture underwent evaporation for oil extraction, and excess water was eliminated with anhydrous sodium sulfate. For Fourier Transform Infrared Spectroscopy (FTIR) analysis using the Bruker Invenio-S FTIR instrument, samples were prepared with dichloromethane and hexane as solvents for the extracted oil. FTIR operated in the MIR ATR Diamond mode, scanning within a wavelength range of 4,000 - 400 cm^{-1} at 4 cm^{-1} intervals, with each scan taking 32 seconds (Bruker, Germany). FTIR spectra of the *d*-limonene solution were used for comparison with the essential oil extracts.

2.7 Statistical analysis

Each experiment was conducted in triplicate, and the results in Tables 1 and 2 were presented as means ± standard deviations (mean ± S.D.). To assess the significance of the mean values, two-way ANOVA was employed, followed by Duncan's post hoc test for pairwise comparisons, with a confidence level of 95%.

3. Results

3.1 Life cycle

Figure 1 illustrates the Kratai Cham plant's maturation and life cycle in saline soils from 2019 to 2022. It was observed that the life cycle within a single season lasts approximately 6 to 8 months, commencing around July and concluding in February (Figure 1). Seedlings emerged during the rainy season, from July to October. Leaves typically sprouted within 3-4 weeks post-germination, occurring between August and November. Branch development followed 2-3 weeks after leaf growth, typically from September to December. The flowering stage initiated 1-2 weeks after the emergence of branches, commencing in late September and concluding between October and December. Fruit formation began 3-4 days post-pollination, with petals wilting and shedding from September to December. Fruit development within the floral structure spanned approximately 3-5 weeks, from October to the following year's January. Subsequently, after fruit development, the plant undergoes senescence, characterized by the withering of leaves, followed by the inflorescence, stem, and roots, typically occurring between November and February in the following year.

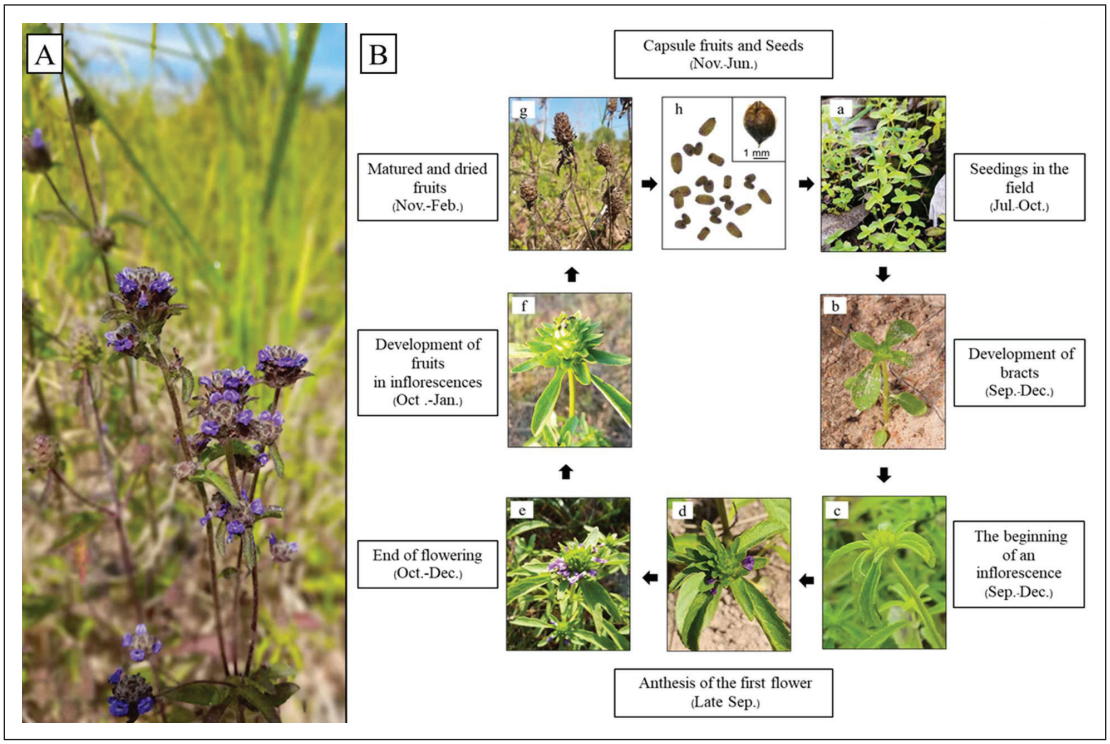

Figure 1. Illustrates the plant morphology of Kratai Cham (A), and its complete life cycle (B) in Hua Na Kham Subdistrict and Khlong Kham Subdistrict, Yang Talat District, Kalasin Province, Thailand, observed from 2019 to 2022. The life cycle encompasses seedling growth (a), bract formation (b), inflorescence development (c-e), fruit maturation (f-g), and seed production (h).

3.2 Soil physicochemical properties

Table 1 presents the physicochemical characteristics of soils in slight-saline and medium-saline regions. During the wet season, the medium-saline region exhibited higher moisture content than the slight-saline area, while bulk density exhibited minimal variation between the two regions. Medium-saline soils featured a lower pH than their slight-saline counterparts. The ECe was significantly higher in the medium-saline region, particularly during the dry season. Furthermore, organic matter content remained relatively low in both regions, with a slight increase observed during the dry season. Sodium and chloride levels were notably elevated in the medium-saline region, whereas potassium levels during the dry season exhibited an opposing trend. Calcium levels displayed significant variations across seasons and regions, while magnesium content was notably higher in the medium-saline region, especially during the wet season.

Table 1. Comparison of soil physicochemical properties between wet and dry season from slight-saline and medium-saline regions.

Soil property	Slight-saline region		Medium-saline region	
	Wet season	Dry season	Wet season	Dry season
Moisture (%)	12.28±0.25^{Bb}	13.23±0.19^{Ba}	15.12±0.21^{Aa}	14.51±0.94^{Ab}
Bulk density (g/cm^3)	1.95±0.09^{Aa}	2.02±0.04^{Aa}	1.92±0.20^{Aa}	2.03±0.13^{Aa}
pH	6.41±0.01^{Ab}	6.84±0.12^{Aa}	6.18±0.01^{Bb}	6.79±0.01^{Aa}
ECe (dS/m)	0.07±0.00^{Bb}	0.48±0.01^{Ba}	0.30±0.02^{Ab}	1.03±0.01^{Aa}
OM (%)	1.45±0.11^{Ab}	2.46±0.19^{Aa}	1.32±0.33^{Bb}	1.96±0.22^{Ba}
Na (mmol/kg)	26.19±0.30^{Ba}	13.10±0.00^{Bb}	34.70±0.29^{Aa}	14.59±0.12^{Ab}
Cl (mmol/kg)	3.33±1.15^{Ab}	16.00±2.00^{Ba}	4.67±1.15^{Ab}	25.33±3.06^{Aa}
K (mmol/kg)	4.25±0.06^{Bb}	7.48±0.01^{Aa}	5.07±0.26^{Aa}	2.94±0.01^{Bb}
Ca (mmol/kg)	12.22±18^{Ba}	5.15±0.25^{Bb}	14.62±0.10^{Ab}	32.26±0.27^{Aa}
Mg (mmol/kg)	4.55±0.11^{Bb}	16.30±0.00^{Ba}	22.05±0.08^{Aa}	17.01±0.03^{Ab}

Note: Values represent mean ± S.D. $^{A, B, etc.,}$ indicate significant inter-group differences, while $^{a, b, etc.,}$ represent significant intra-group differences (p-value < 0.05).

3.3 Leaf epidermal morphology

Table 2 shows the leaf epidermal morphology of Kratai Cham plants grown in slight-saline and medium-saline regions. In salty conditions, stomatal length was notably reduced, especially in the lower epidermis. However, salinity did not significantly harm the quantities of stomatal cells, epidermal cells, capitate trichomes, peltate trichomes, and uniseriate trichomes. All these cell types and trichomes, particularly in the lower epidermis, exhibited significant positive responses to salinity, leading to an increase in their index percentages. Both capitate and uniseriate trichomes displayed minimal variations between the two regions, while peltate trichomes were absent in slight-saline environments.

Table 2. Comparative upper and lower epidermal morphology of Kratai Cham leaves in slight-saline and medium-saline regions.

Traits	Slight-saline region		Medium-saline region	
	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
stomatal length (μm)	35.75±0.84^{Aa}	32.23±1.73^{Ab}	34.55±1.67^{Aa}	27.93±0.76^{Bb}
stomatal cell (no./mm^2)	278.33±60.07^{Bb}	558.33±7.64^{Ba}	410.00±52.68^{Ab}	646.67±7.64^{Aa}
epidermal cell (no./mm^2)	578.33±23.63^{Aa}	596.67±32.15^{Aa}	610.83±60.83^{Aa}	633.33±59.23^{Aa}
uniseriate trichome (no./mm^2)	21.67±2.89^{Aa}	11.67±5.77^{Aa}	23.33±2.89^{Aa}	15.00±5.00^{Aa}
capitate trichome (no./mm^2)	25.00±10.00^{Aa}	25.00±5.00^{Ba}	33.33±5.77^{Aa}	36.67±2.89^{Aa}
peltate trichome (no./mm^2)	ND	28.33±2.89^{A}	ND	31.67±5.77^{A}
stomatal index (%)	32.24±3.90^{Bb}	48.36±1.03^{Aa}	40.15±1.67^{Ab}	50.59±2.38^{Aa}

Table 2. Comparative upper and lower epidermal morphology of Kratai Cham leaves in slight-saline and medium-saline regions. (cont.)

Traits	Slight-saline region		Medium-saline region	
	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
uniseriate trichome index (%)	3.62±0.52^{Aa}	1.93±0.97^{Aa}	3.69±0.39^{Aa}	2.36±0.98^{Aa}
capitate trichome index (%)	4.17±1.73^{Aa}	4.02±0.75^{Aa}	5.23±1.20^{Aa}	5.53±0.94^{Aa}
peltate trichome index (%)	ND	4.55±0.62^{A}	ND	4.73±0.43^{A}

Note: Values represent mean ± S.D. $^{A, B, etc.,}$ indicate significant inter-group differences, while $^{a, b, etc.,}$ represent significant intra-group differences (p-value < 0.05). 'ND' signifies parameter not detected.

3.4 Leaf epidermal anatomy

Figure 2 illustrates the epidermal cell features, stomata, and various trichome types in Kratai Cham leaves grown in medium-saline region. The epidermal cells exhibited either a smooth surface or were coated with a cuticle, presenting jigsaw-like shapes with deeply sculpted cell walls in both the upper and lower leaf epidermis. Stomata presented on both surfaces, characterizing the leaves as amphistomatic, with an anomocytic shape, and surrounded by approximately 3 to 4 subsidiary cells. Two distinct types of trichomes were identified: non-glandular trichomes, including multicellular-uniseriate trichomes, and glandular trichomes, such as capitate and peltate glandular trichomes. The multicellular-uniseriate trichomes consisted of 3 to 8 cells arranged in a single row, featuring a non-flattened structure with a broad base and tapering tip. They varied in length from 223.98 to 1,568 µm, primarily populating the upper epidermis, and were concentrated along leaf veins and the midrib on the lower epidermis. Capitate trichomes comprised 5 to 8 basal cells, short stalk cells, and a single head cell, with relatively small glandular structures measuring around 21.35 to 43.86 µm in diameter. They distributed on both the upper and lower leaf epidermis. In contrast, peltate glandular trichomes were distinctive for their presence within depressions on the epidermal cell layer, comprising 10 to 22 cells. These trichomes encompassed short stalk cells, 8 secretory cells forming an eight-celled apical disc, and a comparatively large spherical secretory head with a diameter ranging from 80.36 to 119.58 µm. Notably, peltate glandular trichomes were exclusively located on the lower leaf epidermis.

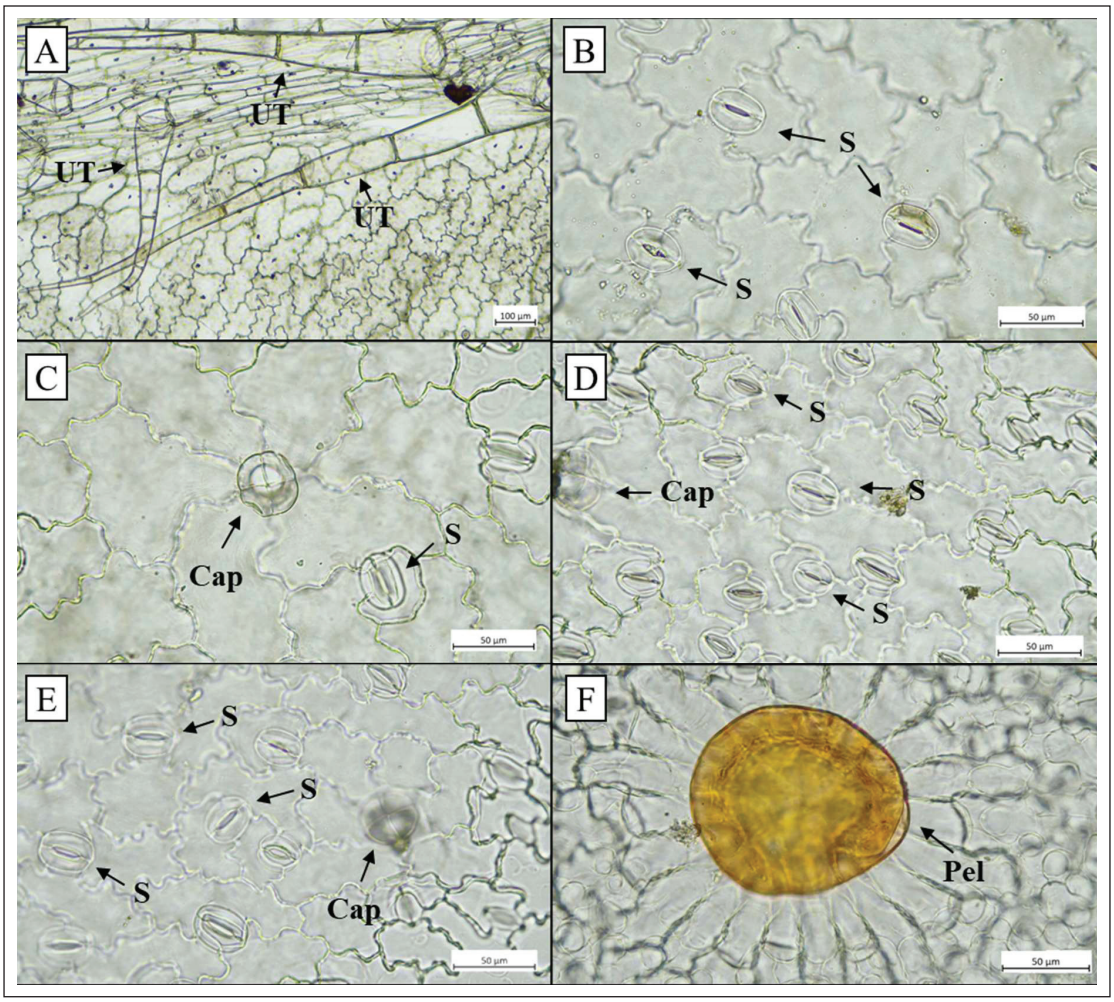

Figure 2. The upper (A-C) and lower (D-F) leaf epidermis of Kratai Cham grown in medium-saline region, highlighting key features such as capitate glandular trichome (Cap), peltate glandular trichome (Pel), stomata (S), and uniseriate non-glandular trichome (UT).

3.5 FTIR spectra of essential oils

Figure 3illustrates the chemical structure analysis of the essential oil extracted from Kratai Cham leaves using FTIR spectroscopy, with hexane maceration and steam distillation. The experimental results revealed that the FTIR spectra of the extracted essential oil predominantly exhibited peaks within a specific wave number range. Similar peaks were observed in both the slight-saline and medium-saline regions. These peaks were identified at wave numbers ranging from 2964.44 cm^{-1} to 2858.28 cm^{-1}, corresponding to the C-H stretching of methyl (-CH_3) and methylene (-CH_2-) in alkene. Additionally, there were peaks at wave numbers ranging from 1673.81 cm^{-1} to 1672.07 cm^{-1}, indicative of C=C bond stretching in alkene. However, the peaks from the medium-saline region exhibited a greater shift compared to those from the slight-saline region, a pattern observed in all the various extracts. Nevertheless, upon comparison with the wave numbers of *d*-limonene, it was evident that the

only overlapping or closely similar wave number was within the range of 2964.44 cm^{-1} to 2858.28 cm^{-1}, corresponding to C-H stretching.

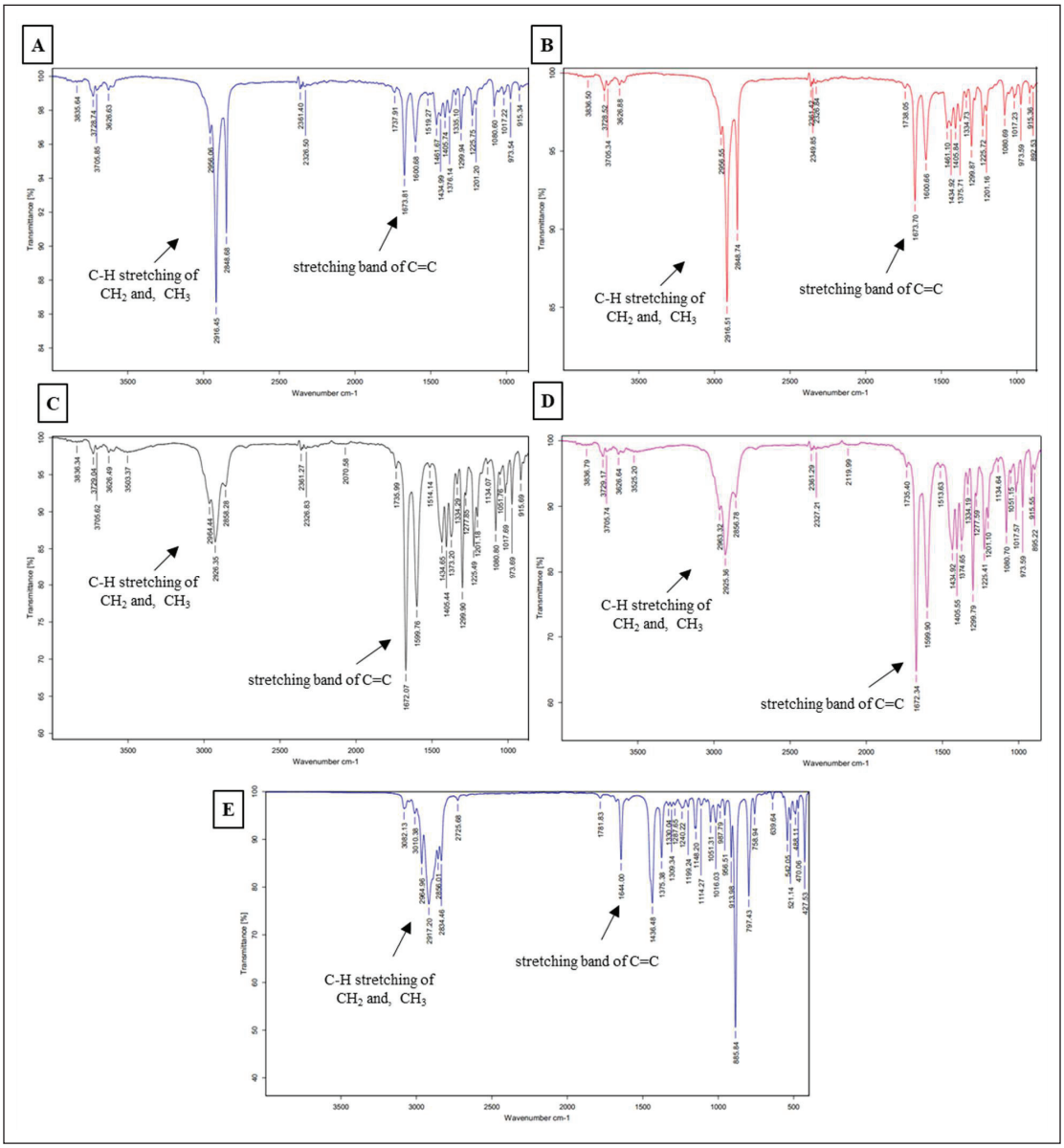

Figure 3. FTIR spectra of essential oils extracted from Kratai Cham leaves using hexane maceration (HM) and steam distillation (SD). HM extracts from slight-saline region (A) and medium-saline region (B), as well as SD extracts from slight-saline region (C) and medium-saline region (D), are compared with (E) *d*-limonene.

4. Discussion

Our examination of Kratai Cham's life cycle revealed a prolonged flowering period from late September to December, in contrast to earlier reports. Jayaweera (1982) indicated a November flowering, while Wu & Raven (1998), Kumar *et al*.

(2020), and Ye *et al*. (2022) observed flowering from September to November. In contrast, the World Health Organization. Regional Office for the Western Pacific (1990), reported an earlier flowering period from April to July. We attributed the variations primarily to the influence of salt and drought stress. We observed salt crystals on the soil surface during Kratai Cham's growth in medium-saline regions, particularly during the fruit development phase from November to February. Notably, the plant demonstrated resilience to high soil sodium concentrations, especially during the wet season when levels reached 34.70 mmol Na/kg (Table 1). Consequently, we speculated that salinity may impeded seed germination or extend germination periods in saline conditions. This could adversely affect plant development, as energy was diverted towards mitigating sodium toxicity, generating compatible compounds, modulating osmotic potentials, and eliminating free radicals, as supported by previous research (Jullapong *et al*., 2015; Fakthongphan, 2016; Cirka *et al*., 2021; Pavli *et al*., 2021).

In response to salt stress, plants typically undergo physiological adjustments in their leaf epidermal tissues to mitigate water loss and restrict the accumulation of harmful ions. For instance, basil (*Ocimum basilicum* L.) subjected to salinity levels of 100-200 mM NaCl exhibited a reduction in stomatal density compared to the control treatment (Barbieri *et al*., 2012). Similarly, strawberry (*Fragaria ananassa* L.) and quinoa (*Chenopodium quinoa* Willd.), exposed to salinity stress for 7-8 weeks at 40 mM NaCl and 400 mM NaCl, respectively, showed a decrease in stomatal density (Hasanuzzaman *et al*., 2023). On the other hand, certain plant species adapted by decreasing stomatal size while increasing stomatal density to enhanced salt tolerance (Balasubramaniam *et al*., 2023; Hasanuzzaman *et al*., 2023)resulting in significant losses to global crop production. Consequently, there is a strong need to develop stress-tolerant crops with a higher water use efficiency through breeding programs. Water use efficiency could be improved by decreasing stomatal transpiration without causing a reduction in CO2 uptake under osmotic stress conditions. The genetic manipulation of stomatal density could be one of the most promising strategies for breeders to achieve this goal. On the other hand, a substantial amount of water loss occurs across the cuticle without any contribution to carbon gain when the stomata are closed and under osmotic stress. The minimization of cuticular (otherwise known as residual. Barley (*Hordeum vulgare* L.) and wild barley (*Hordeum spontaneum* L.), subjected to 200-300 mM NaCl for 7-8 weeks, maintained or increased stomatal density (Hasanuzzaman *et al*., 2023; Kiani-Pouya *et al*., 2020). In our study, the ECe level in the medium-saline region (Table 1) fallen into the "Slight" salt category as per the USSL Staff (1954). This slight salinity significantly influenced the leaf epidermal morphology of Kratai Cham, particularly by reducing stomatal size and increasing stomatal density, with a more pronounced effect on the lower epidermis (Table 2).

The role of trichome types in plant adaptation to diverse stress conditions varies, with a stronger link observed between glandular trichomes and salt stress resilience compared to non-glandular trichomes. Species within the Lamiales Order, like basil, which notably features glandular trichomes, showed a significant increase in

the density of capitate and peltate trichomes under salt stress conditions (Baran *et al*., 2010; Lyudmila *et al*., 2018; Michael, 2013). This aligns with findings that the density of glandular trichomes on both upper and lower leaf surfaces increased under stress conditions in plants like Japanese Catnip (*Schizonepeta tenuifolia* Briq.) exposed to 50-100 mM NaCl (Zhou *et al*., 2018) and Vietnamese Mint (*Mentha pulegium* L.) after 5 weeks of exposure to 50 mM NaCl until flowering (Karray-Bouraoui *et al*., 2009). In our current study, we observed a significant increase in the numbers and indices of capitate and peltate trichomes in Kratai Cham leaves, particularly in the lower epidermis (Table 2). In contrast, non-glandular trichomes, such as uniseriate trichomes, were reported to primarily serve as protection against herbivory and insect oviposition and to reduce water loss under heat stress (Karabourniotis *et al*., 2020; Santos Tozin *et al*., 2016). In this study, we noted an increase in the numbers and indices of uniseriate trichomes in Kratai Cham leaves in medium-saline region, especially in the upper epidermis (Table 2). This increase may contribute to water retention in plant cells, potentially influenced by both salt stress and the unique characteristics observed in the upper epidermis.

Salt stress was presumed to boost the synthesis of essential oils in Kratai Cham leaves, correlating with heightened counts and indices of glandular trichomes (Table 2) and notable FTIR spectrum peak shifted specific to *d*-limonene (Figure 3). Analysis of the leaf essential oil through gas chromatography-mass spectrometry (GC-MS) unveiled constituents like limonene (20.59-35.07%), fenchone (15.79-31.81%), caryophyllene (6.98-10.32%), and piperitenone oxide (1.96-11.63%) (Zeng *et al*., 2013). Additionally, limonene exhibited distinct peaks in FTIR spectra in the range of 1644 cm^{-1} to 1640.00 cm^{-1}, associated with C=C band stretching, and others present at 1309,1217, 956, 913 and 885 cm^{-1} (Alipanah *et al*., 2021; Derdar *et al*., 2019). Notably, shifts in FTIR spectrum peaks of Kratai Cham leaf essential oil in our study, extracted using hexane maceration and steam distillation, were observed, and the reduction or disappearances of some peaks, possibly linked to salt stress or impurities in the oil extracts (Figures 3). Prior research underscored the impact of salt stress on altering the composition of synthesized compounds, as exemplified by Japanese Catnip, which experienced marked reductions in sesquiterpenes and monoterpenes but elevated esters and terpenoids when subjected to highly concentrated salt solutions (50-100 mM NaCl) (Zhou *et al*., 2018).

5. Conclusion

In conclusion, this study, spanning three years (2019-2022), illuminated the life cycle and adaptations of the Kratai Cham plant in saline soils. This plant demonstrated a remarkable capacity for resilience and adaptation. Soil analysis revealed significant differences between slight-saline and medium-saline regions regarding moisture, pH, ECe, and elemental composition. Examining leaf epidermal morphology highlighted the plant's ability to modify stomatal length and trichome characteristics, particularly in the lower epidermis, as a response to salinity. Additionally, the chemical analysis of extracted essential oil through FTIR spectroscopy unveiled distinctive spectral

features, particularly in *d*-limonene. These findings contributed valuable insights into Kratai Cham's adaptability and chemical properties, with potential implications for its medicinal utility in saline environments.

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