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Allelopathic effects of *Ageratum conyzoides* L. on the germination and growth of *Zea mays* L., *Lactuca sativa* L. and *Solanum lycopersicum* L.

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ABSTRACT

We evaluated the allelopathic potential of *Ageratum conyzoides* L. aqueous leaf extracts on germination and growth of *Solanum lycopersicum* L. (tomato), *Zea mays* L. (corn) and *Lactuca sativa* L. (lettuce). Total phenolic content (TPC) of the soil rhizosphere was determined by spectrophotometry method. We also investigated the habitat attributes (e.g., canopy openness and leaf area index (LAI)) of *A. conyzoides* infested region. Results revealed that aqueous leaf extracts had both inhibitory and stimulatory effects on the germination, plumule length and radicle length of crops. All extract concentrations inhibited the germination of *Z. mays* and *L. sativa* seeds, but no effects on *S. lycopersicum*, except at 50 gL^{-1}. Conversely, plumule and radicle lengths were stimulated in *S. lycopersicum* and *L. sativa* for majority of extract concentrations but they were inhibited in *Z. mays*. The inhibitory allelopathic effects of *A. conyzoides* were maximum in *Z. mays* (i.e., *S. lycopersicum* < *L. sativa* < *Z. mays*). TPC values in invaded soil were 0.046 g/L and 0.48 g/L with gallic acid and catechol, respectively. This study showed that the presence of allelochemicals in *A. conyzoides* invaded soil, which potentially influenced the crops, thereby validating the 'novel weapon (NW) hypothesis'. The recorded values of habitat attributes were associated with the successful spread of *A. conyzoides* and hence, its allelopathic effects on test crops.

Keywords: *Ageratum conyzoides* L., agroecosystems, allelopathy, aqueous extracts, canopy gap analysis, corn, crop growth, *Lactuca sativa*, lettuce, novel weapon (NW) hypothesis, *Solanum lycopersicum*, tomato, *Zea mays*.

INTRODUCTION

Invasive plants threaten native biodiversity, global agriculture systems, and impact human well-being (21,24). The impacts of plant invasion on agroecosystems significantly influences global food security, agrarian economy, and climate-smart agriculture (9,31). Invasive plant decreases crop yield's due to phenomenon of allelopathy (16). Allelopathy is in fact 'biotic interference through release of bio-active molecules or secondary metabolites' which is much pronounced in agriculture systems (2,34). Allelopathy in agroecosystems is associated with the 'novel weapon (NW) hypotheses' proposed for the successful spread of invasive plants (5).

A. conyzoides ('Billy goat weed') is an annual invasive plant, native to tropical America and now naturalized in Africa, Asia, and the South Pacific Islands (13) (Figure 1a). Its plant contains vast array of secondary metabolites [alkaloids, flavonoids, chromenes, benzofurans, and terpenoids], which may impart allelopathic effects on neighbouring crops (7). *S. lycopersicum* is selected as the test crop because it is cultivated in large areas, has antioxidant potential and is widely consumed crop, with an annual global production of 170

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million t (8). *Z. mays* is staple crop in some regions of Latin America, Africa, and Asia (9). *L. sativa* is popular salad crop in both the fresh and ready-to-eat global market, it is rich in minerals and bioactive chemicals (17).

Figure 1. a. Field photograph of individual *Ageratum conyzoides* plant, b. field photograph of the study area invaded by *Ageratum conyzoides* (photo courtesy R.B. Syngkli)

Several studies in past attempted to analyse the impacts of invasive plants on native biodiversity, agriculture, and human well-being (19,23). However, only a few studies explored the allelopathic effects of invasive plants on food crops in terms of their above and belowground biomass (33). Further, previous studies attempted to assess the effects of aqueous extracts and decomposed organs of widely investigated invasive plants (e.g., *Parthenium hysterophorus* L. and *Mikania micrantha* Kunth.) only on the germination and growth of crops (12,33). However, the studies assessing the impacts of emerging plant invaders such as *A. conyzoides* on edible crops are inadequate (13). Moreover, allelopathic studies on agricultural crops are especially scant in Mizoram, India (22). Therefore, the present article aims to fill the existing knowledge gap by investigating the allelopathic effects of *A. conyzoides* on selected crops of wide dietary intake and nutritional value. In this respect, the analysis of major allelochemicals and their linkage with the habitat attributes of *A. conyzoides* (such as light intensity, canopy gap analysis, and leaf area index (LAI)) was studied which is rather novel approach in the ecological investigation of allelopathy. Henceforth, this article aimed to evaluate the allelopathic potential of *A. conyzoides* by the (i) Phytotoxic effects of the leaves on the growth of three selected crops i.e., *S. lycopersicum*, *Z. mays*, and *L. sativa* and (ii) Total phenolic content (TPC) of the soil. We analyzed the canopy cover, LAI, and light intensity of the invaded area to establish their interrelationship with the spread and allelopathic effects of *A. conyzoides*.

MATERIALS AND METHODS

Study site and sample collection

The study was conducted at Aizawl, Mizoram, North East India (23.87 ºN 92.89 ºE), altitude 800 m to 1200 m (20). Annual rainfalls 2350 mm. Temperature: 20 and 35 °C in summer and between 9 and 21 °C in the winter. The study was done at Mizoram University, Tanhril (23.73784167ºN 92.66741944ºE), Mizoram, India, 846 m above sea level. The study was conducted during March and April, 2023. The leaves of *A. conyzoides* were collected from the roadside invaded region (Figure 1b). The soil samples were collected from the invaded region using the zig-zag method. The soil was dug upto 15 cm depth from the rhizosphere using a shovel and kept in a clean plastic tray (3). Unwanted materials or debris such as roots, stones, leaves, and plant materials were removed. The soil was air-dried and sieved by 2 mm sieve. The study site soil had pH of 5.5, temperature : 25 ºC, ambient light : 35.34 LUX.

Preparation of aqueous leaf extracts

The aqueous leaf extract of *A. conyzoides* was prepared as per method of Ismail and Chong (11) with slight modification. Fresh leaves were collected and chopped into small pieces to keep them in a conical flask. Further, 100 ml distilled water was added into the flask and agitated in a rotary shaker (Rotary Flask Shaker, Scientech, Science Enterprises, Delhi, India) at 140-150 RPM for 18 h. The aqueous extract was then filtered through 2 layers of filter papers (Whatman No. 41) and maintained it eventually into 4 concentrations (i.e., 50 gL^{-1}, 37.5 gL^{-1}, 25 gL^{-1}, and 12.5 gL^{-1}). Besides, these concentrations of aqueous extracts, a control (distilled water) was used to compare the results. The petri dishes (90 x 15 mm) were lined with filter paper to act as medium to absorb the leaf extracts (11). Ten seeds of *Z. mays*, *S. lycopersicum* and *L. sativa* were kept in petri dishes. Five mL of different extract concentrations and control were added in petri dishes and covered with the filter papers. All experiments were done in duplicate. The petri dishes were covered and incubated B.O.D Incubator, at 30º C for 4 days. Figure 2 showed the seed germinations and the growth of test crops after the incubation period. The seed germination %, radicle, and plumule length of the test crops were measured to compare the effects of *A. conyzoides* based leaf extracts in comparison to control.

Total phenolic content (TPC)

The quantification of TPC was done in triplicate as per the methods by Akomeng and Adusei (1) and Swain and Hills (28), with some modifications by using gallic acid and catechol as a standard. Twenty g soil samples were taken and kept in a conical flask containing 100 mL distilled water which is a solvent for extraction. The soil samples were agitated for 1 h in a Rotary shaker and kept for 24 h at room temperature. The supernatant was filtered through filter paper (Whatman No. 41) to remove the leaf debris. For TPC analysis using gallic acid as a standard, 0.5 mL aliquot of 1, 2.5, 5, 7.5, and 10 mg/L concentrations were used. Variable concentrations were then mixed with 2 mL of Folin-Ciocalteu reagent (1:10 ratio with distilled water). The mixture was further neutralized with 4 ml sodium carbonate solution (7.5 %) and incubated at room temperature for 30 min with

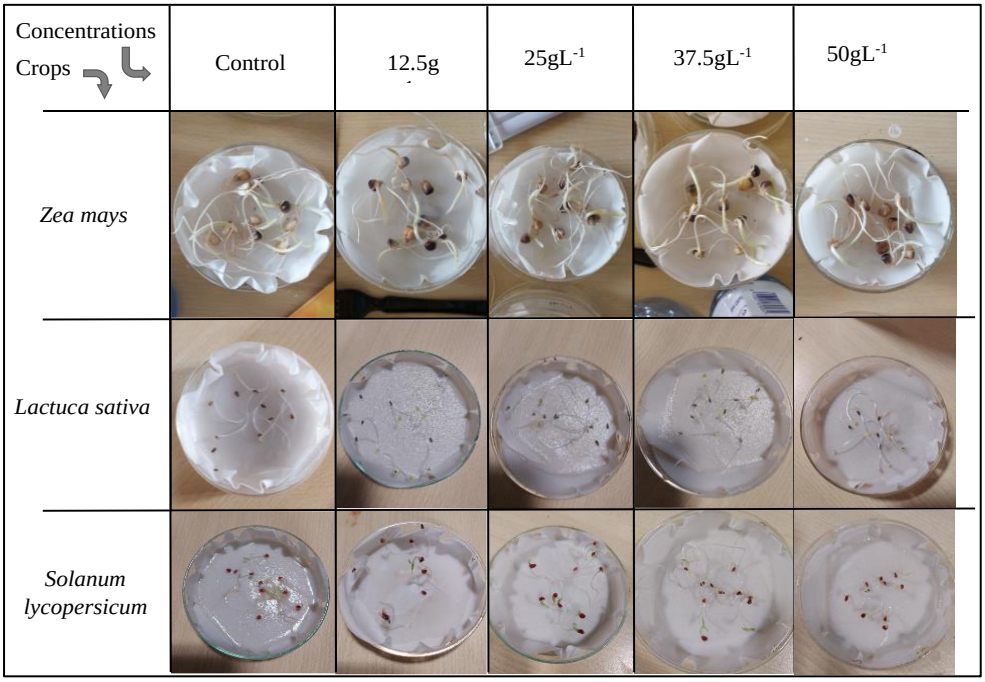

Figure 2. Germinated seeds of *Zea mays*, *Lactuca sativa*, and *Solanum lycopersicum* on different concentrations of *A. conyzoides* aqueous leaves extract after 4 days of incubation at 30 ºC.

intermittent shaking for colour development. The absorbance of blue color was measured at 765 nm with a UV-visible spectrophotometer (Microprocessor UV-VIS Double Beam Spectrophotometer, Igene Labserve). For TPC analysis, catechol was a standard, 1 mL aliquot of 1, 2.5, 5, 7.5, and 10 mg/L concentrations were used and then mixed with 1 mL of Folin-Ciocalteu reagent (50 %). Reaction mixtures were further neutralized with 1 mL of sodium carbonate solution (20 %) and incubated at room temperature for 30 min with intermittent shaking to facilitate color development. Finally, the absorbance was taken at 700 nm with a UV-visible spectrophotometer (Microprocessor UV-VIS Double Beam Spectrophotometer, Igene Labserve). The concentrations and absorbance values of TPC were determined from the standard calibration curve of gallic acid and catechol.

Canopy openness, leaf area index and light intensity of invaded site

The canopy openness of *A. conyzoides* infested site was analyzed by hemispherical photography and gap light analyzer (GLA) software method, as devised by Sooraj *et al*. (26). The hemispherical photographs were taken in a skyward direction perpendicular to the ground using a fish eye lens (Skyvik Sign One 10mm Fisheye Lens) mounted on a smartphone (Samsung Galaxy M51). Hemispherical photos were taken in duplicate from 5 areas (i.e., FC1, FC2, FC3, FC4, and FC5) on a cloudy day to select 1 best photograph to act as an input to GLA software for canopy gap analysis (Figure 3). Coordinates and elevation of the site were taken using GPS (Garmin GPSMAP 64s). The magnetic correction in the configuration settings of GLA was taken from the NOAA website. The light intensity

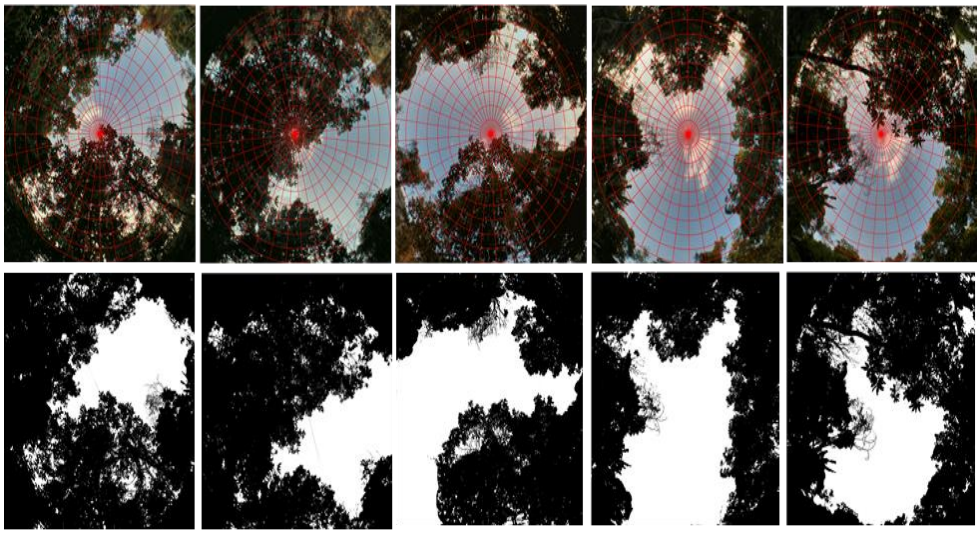

Figure 3. Hemispherical photos are used to estimate canopy openness. The colour photos are the original photos taken and the monochrome photos are the processed photos (after adjusting the settings) used for and analyzing canopy openness on GLA

and LAI of the area were measured using a plant canopy analyzer (Integration of handheld and Software from Kaizen Imperial and Quantum Sensors from Apogee Instruments, USA) from five random spots under the forest canopy. The data of plant canopy analyzer were recorded and stored in the handheld device attached to the sensors which were later extracted using Kaizen software. Herein, plant canopy analyzer data and hemispherical photographs were collected to facilitate the study on the habitat ecology and further elucidate the role of canopy gaps in influencing the invasive spread of *A. conyzoides*, which might be tightly linked with its allelochemical attributes.

Statistical Analysis

The statistical analyses were performed in M.S Excel 2019 software. Statistical analysis was performed for the recorded data or for various treatments to assess their validity and significance. Standard deviation values of experimental results were calculated and reflected in the graphs. Additionally, the Pearson correlation was used to assess the relationship between canopy openness, light intensity (diffused PAR), and LAI of the invaded region.

RESULTS AND DISCUSSION

Seed germination

Low and moderate concentrations of *A. conyzoides* leaves extract (12.5 gL^{-1}, 25 gL^{-1}, and 37.5 gL^{-1}) did not affect the seed germination of *S. lycopersicum*, but higher concentration (i.e., 50 gL^{-1}) caused 5 % reduction than control (Figure 4). However, *Z. mays* and *L. sativa* showed a significant reduction in germination by 30 % and 26.32 %, even at lowest concentration (12.5 gL^{-1}). Seed germination in *Z. mays* was inhibited by 40 % at

higher concentrations (25 gL^{-1} and 37.5 gL^{-1}). Whereas, the decrease in seed germination of *L. sativa* was 15.79 % at 25 gL^{-1}, while reduction was 5.26 % at 37.5 gL^{-1}. Higher concentration (50 gL^{-1}) significantly reduced seed germination of *Z. mays* and *L. sativa* by 30 % and 10.53 %, respectively, over control. Among the test crops, *Z. mays* seed germination was significantly reduced while, *S. lycopersicum* germination was least affected crop (Figure 4).

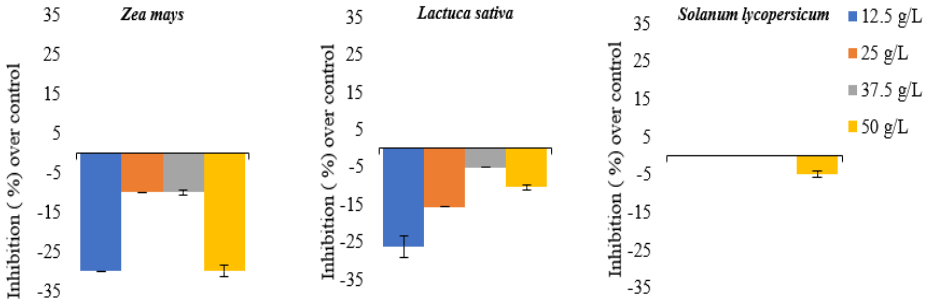

Figure 4. Allelopathic effect of *A. conyzoides* extracts on germination of *Zea mays*, *Lactuca sativa*, and *Solanum lycopersicum.*

The inhibition of seed germination was maximum in *Z. mays* followed by moderate inhibition in *L. sativa*, while *S. lycopersicum* showed least inhibition, except slight reduction at 50 gL^{-1}. Similar results were also observed in previous studies of Singh (25), where *A. conyzoides* extract inhibited the germination of *Pisum sativum* L. Similarly, application of fresh and dry leaf extract of *A. conyzoides* reduced the seed germination of *Oryza sativa* L. (18).

Seedlings growth

The plumule length of *S. lycopersicum* and *L. sativa* was stimulated. The 25 gL^{-1} concentrations showed the most stimulatory effects in *S. lycopersicum* (59 %) and *L. sativa* (70 %). However, *A. conyzoides* extract were inhibitory to *Z. mays* at all concentrations, except that 50 gL^{-1} had positive effect (10.2 %) (Figure 5). However, the radicle length of

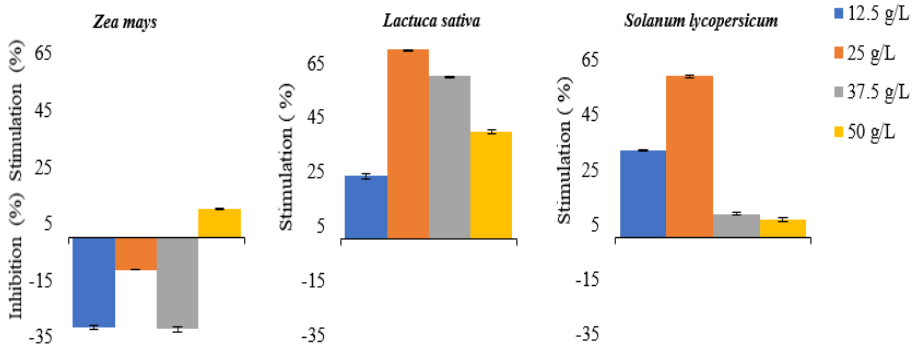

Figure 5. Allelopathic effect of *A. conyzoides* extracts on plumule elongation of *Zea mays*, *Lactuca sativa*, and *Solanum lycopersicun*

S. lycopersicum showed stimulatory or positive effects at 12 gL^{-1}, 25 gL^{-1}, and 50 gL^{-1} concentrations but negative effects at 37.5 gL^{-1} concentrations. The radicle length of *Z. mays* showed negative effects at 12 gL^{-1}, 25 gL^{-1}, and 37.5 gL^{-1} concentrations, except that 50 gL^{-1} concentration had positive effect (1 %). In *L. sativa*, the radical length showed positive effects at all concentrations and 25 gL^{-1} concentration was most stimulatory (18.6 %) (Figure 6).

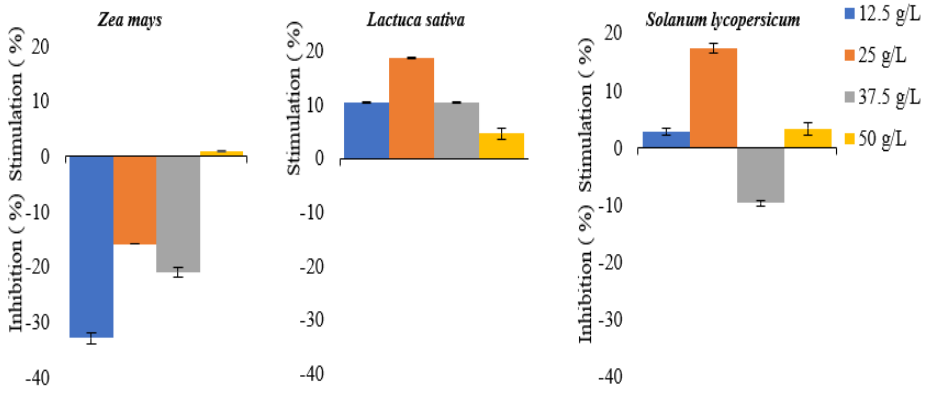

Figure 6. Allelopathic effect of *A. conyzoides* extracts on radicle elongation of *Zea mays*, *Lactuca sativa*, and *Solaum lycopersicum*.

The aqueous leaves extract of all concentrations stimulated the plumule length of *L. sativa* and *S. lycopersicum*. In *Zea mays,* the low extract concentrations inhibited the radicle length, while higher concentrations were stimulatory. On the contrary, *S. lycopersicum* had negative effects only at 37.5 gL^{-1} concentration but other concentrations were stimulatory. Results further revealed that both radicle and plumule length of *Z. mays* were decreased at all the concentrations, except at 50 gL^{-1}. Overall, *A. conyzoides* exhibited both positive (stimulatory) and negative (inhibitory) effects on the test crops. Present study corroborates findings of Syngkli *et al*. (29) which also noted the stimulatory as well as inhibitory effects of *A. conyzoides* on seed germination of *L. sativa*. Also, the results of present study were well supported by Negi *et al*. (18) where *A. conyzoides* leaves extract promoted the growth of the shoot and roots of *O. sativa*. Additionally, Idu and Oghale (10) also found that the flower, root, and leaf extract of *A. conyzoides* have stimulatory effects on the plumule and radical length of *Sesanum indicum* L. Several studies observed that leaf leachates of *A. conyzoides* enhances the soil nitrogen content and thus can be used as green manure to replace excessive use of synthetic N fertilizers (4,14,18). However, in our case, *A. conyzoides* based leaf extract exhibited both stimulatory and inhibitory effects, therefore, should not be used as bio-fertilizer in agriculture.

Invaded site Canopy openness, light intensity and leaf area index

The total canopy openness of the selected study site was 40.46 %. The highest canopy openness was observed at FC4 (53.07 %), while the lowest was recorded at FC2 (28.98 %) (Table 1). The total incoming PAR of the study site was 29.2 (±0.8) µ mol m^{-2} s^{-1}, which is the total solar radiation received by the area above the forest canopy. Whereas, the total

diffused PAR of the study site was 20.8 (±6.6) μ mol m^{-2} s^{-1}, which is the total solar radiation received by the area under the forest canopy. The highest diffused PAR was observed at FC4 (29 μ mol m^{-2} s^{-1}), while it was lowest at FC2 (14 μ mol m^{-2} s^{-1}). The total LAI of the invaded study site was 0.63 (±0.4) (Table 1). LAI was highest at FC2 (1.155), while the lowest was at FC4 (0.055) (Table 1).

Table 1. Canopy openness, light intensity and leaf area index of the forest cover on the *Ageratum conyzoides* invaded regions.

Sl. No	Code	Canopy gap openness (%)	Incoming PAR *μ mol m^{-2} s^{-1}*	Diffused PAR *μ mol m^{-2} s^{-1}*	Leaf Area Index
1	FC1	33.2	30	15	1.097
2	FC2	28.98	30	14	1.155
3	FC3	46.14	29	26	0.237
4	FC4	53.07	38	29	0.055
5	FC5	40.91	29	20	0.618
Mean ±SD		**40.46±9.7**	**29.2±0.8**	**20.8±6.6**	**0.6324±0.4**

FC1 (Forest canopy 1), FC2 (Forest canopy 2), FC3 (Forest canopy 3), FC4 (Forest canopy 4), and FC5 (Forest canopy 5) were 5-regions of the study area where the hemispherical photographs, incoming and diffused PAR, and LAI were taken for canopy gap analysis.

Statistical analysis, as demonstrated through the correlation matrix, showed a highly significant positive relationship of the canopy openness with light intensity (r = 0.99), while a highly significant negative relationship was observed with LAI (r = -0.99) (Table 2). Statistical analysis further revealed a highly significant negative correlation between light intensity and LAI (r = -1.00) (Table 2). These results together confirmed that *A. conyzoides* was present in an open area with sufficient solar radiation and scant forest canopy cover. Large canopy openness, high light intensity, and low forest canopy cover are the factors that reflect the disturbed status of the selected site, which can be suited to deploy

Table 2. Correlation of Canopy openness, Light intensity (Diffused PAR), and Leaf area index in the *Ageratum conyzoides* invaded the area.

Correlation	Canopy openness	Light Intensity	Leaf Area Index
Canopy openness	1		
Light Intensity	0.99	1	
Leaf Area Index	-0.99	-1.00	1

ecological traits/mechanisms of invasive plants, thereby increasing the diversity and distribution of *A. conyzoides* (3,26,27). Moreover, increased light availability influences microbial activity, nutrients mineralization, and physicochemical attributes in the soil, thereby making the site congenial for *A. conyzoides* invasion (11). Therefore, agricultural fields rich in soil nutrients are well-suited for *A. conyzoides* invasion.

Total phenolics content (TPC)

The TPC of the soil was recorded as 0.046 mg/L and 0.048 mg/L by using gallic acid and catechol standards, respectively (Table 3). The presence of TPC in the rhizosphere soil showed that *A. conyzoides* releases allelochemicals in the soil which potentially influence

Table 3. Total phenolic content of soil extracts by gallic acid and catechol at different wavelengths.

Standard	Concentration (mg/L)	Absorbance (nm)	Wavelength (nm)
Gallic Acid	0.046±0.003	0.008±0.001	760
Catechol	0.048±0.003	0.029±0.002	700

Each value represents the mean (± standard deviation) of three replicates.

neighbouring crops and native vegetation. Allelochemicals are released into the environment through leaching, from plant foliage, and volatilization roots exudates and decomposition of dead plant residues (6,32). In present study, allelochemicals (e.g., TPC) present in the soil were recorded in trace amount. However, previous studies also corroborate our results by demonstrating that even trace amount of allelochemical can adversely influence the germination and growth of test crops (13,16,18). Present study further revealed that quantitative estimation of TPC with two varying methods i.e., one by using gallic acid while other employing catechol as a standard, showed comparable results and therefore, can be used in future studies on allelopathy.

CONCLUSIONS

A. conyzoides aqueous extracts had both inhibitory and stimulatory allelopathic effects on test crops depending on the stress tolerance of test crops and their subsequent responses when exposed to allelochemicals. Inhibitory effects of *A. conyzoides* based allelochemicals on the seed germination of the test crops were observed as *S. lycopersicum* < *L. sativa* < *Z. mays*. However, *L. sativa* and *S. lycopersicum* showed stimulatory effects on seedling growth i.e., plumule and radicle length. This study concluded that the *A. conyzoides* derived leaf leachates should not be used as bio-fertilizer/green manure in agroecosystems due to their adverse influence on seed germination. The canopy openness and light availability indicated the disturbance status, which facilitated the spread of *A. conyzoides* and may be linked with its allelopathic potential. In respect of allelopathy, future studies can cover detailed characterization of allelochemicals in *A. conyzoides* with the elucidation of bioassay activities on selected crops to effectively validate the novel weapon (NW) hypothesis. There is need to effectively control invasive spread of *A. conyzoides* and sustain crop growth and yield.

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CONFLICT OF INTEREST

The authors announce that they have no conflict of interest.

DECLARATION

We declare that all authors of this manuscript have made substantial contributions. We have not excluded any author that substantially contributed to this manuscript. We have followed the ethical norms established by our respective institutions.

AUTHORS CONTRIBUTION

R.B. Syngkli: Methodology, Investigation, Data curation, Formal analysis; Prabhat Kumar Rai: Conceptualization, Methodology, Data curation, Formal analysis, Writing - review & critical editing; Supervision.

REFERENCES

1. Akomeng, N. and Adusei, S. (2021). Organic solvent extraction and spectrophotometric quantification of the total phenolic content of the soil. *Heliyon* **7(11)**: e08388.
2. Alvarado, A.M., Aguirre-Becerra, H., Vázquez-Hernández, M.C., Magaña-Lopez, E., Parola-Contreras, I., Caicedo-Lopez, L.H., Contreras-Medina, L.M., Garcia-Trejo, J.F., Guevara-Gonzalez, R.G. and Feregrino-Perez, A.A. (2019). Influence of elicitors and stressors on the production of plant secondary metabolites. *Natural Bio-active Compounds: Production and Applications* **1**: 333-388.
3. Andreou, G.M., Messer, M., Tong, H., Nikoloski, Z. and Laitinen, R.A. (2023). Heritability of temperature-mediated flower size plasticity in *Arabidopsis thaliana*. *Quantitative Plant Biology* **4**: e4.
4. Anhar, A., Junialdi, R., Zein, A., Advinda, L. and Leilani, I. (2018). Growth and tomato nutrition content with *Ageratum conyzoides* L applied. In: *IOP Conference Series: Materials Science and Engineering* **335(1)**: 012017. The 2nd International Conference on Mathematics, Science, Education and Technology. Padang, West Sumatera, Indonesia.
5. Callaway, R.M. and Ridenour, W.M. (2004). Novel weapons: Invasive success and the evolution of increased competitive ability. *Frontiers in Ecology and the Environment* **2(8)**: 436-443.
6. Choudhary, C.S., Behera, B., Raza, M.B., Mrunalini, K., Bhoi, T.K., Lal, M.K., Nongmaithem, D., Pradhan, S., Song, B. and Das, T.K. (2023). Mechanisms of allelopathic interactions for sustainable weed management. *Rhizosphere* 100667.
7. Erida, G., Ichsan, C.N., Kurniawan, T., Khan, I.H. and Javaid, A. (2023). Potential of secondary metabolites of *Ageratum conyzoides* L. in weed management: A review. *Allelopathy Journal* **58(1):** 23-40.
8. FAO (Food and Agriculture Organization of the United Nations). https://www.fao.org/faostat/en/#data/QCL (accessed on 20-06-2023)
9. Hussain, M.I., Abideen, Z., Danish, S., Asghar, M.A. and Iqbal, K. (2021). Integrated weed management for sustainable agriculture. *Sustainable Agriculture Reviews* **52**: 367-393.
10. Idu, M. and Oghale, O.U. (2013). Studies on the allelopathic effects of aqueous extract of *Ageratum conyzoides* Asteraceae on seedling growth of *Sesanum indicum* L. (Pedaliaceae). *International Journal of Science, Environment* **2**: 1185-1195.
11. Ismail, B.S. and Chong, T.V. (2002). Effects of aqueous extracts and decomposition of *Mikania micrantha* HBK debris on selected agronomic crops. *Weed Biology and Management* **2(1)**: 31-38.
12. Jali, P., Samal, I.P., Jena, S. and Mahalik, G. (2021). Morphological and biochemical responses of *Macrotyloma uniflorum* (Lam.) Verdc. to allelopathic effects of *Mikania micrantha* Kunth extracts. *Heliyon* **7(8)**: e07822.
13. Kaur, A., Kaur, S., Singh, H.P., Datta, A., Chauhan, B.S., Ullah, H., Kohli, R.K. and Batish, D.R. (2023). Ecology, biology, environmental impacts, and management of an agro-environmental weed *Ageratum conyzoides*. *Plants* **12(12)**: 2329.
14. Kumar, A., Kumar, N., Kumar, K. and Asma. (2018). Allelopathic assessment of *Ageratum conyzoides* weed on *Pisum sativum* L. *International Journal of Recent Scientific Research* **9(6)**: 27566-27570.

15. Liu, Y., Oduor, A.M., Zhang, Z., Manea, A., Tooth, I.M., Leishman, M.R., Xu, X. and Van Kleunen, M. (2017). Do invasive alien plants benefit more from global environmental change than native plants? *Global Change Biology* **23(8)**: 3363-3370.
16. Liu, Z., Zhang, N., Ma, X., Zhang, T., Li, X., Tian, G., Feng, Y. and An, T. (2022). Sesquiterpenes from *Ambrosia artemisiifolia* and their allelopathy. *Frontiers in Plant Science* **13**: 996498.
17. Medina-Lozano, I., Bertolín, J.R. and Díaz, A. (2021). Nutritional value of commercial and traditional lettuce (*Lactuca sativa* L.) and wild relatives: Vitamin C and anthocyanin content. *Food Chemistry* **359**: 129864.
18. Negi, B., Bargali, S.S. and Bargali, K. (2020). Allelopathic interference of *Ageratum conyzoides* L. against rice varieties. *Current Agriculture Research Journal* **8(2)**: 69-76.
19. Pyšek, P., Hulme, P.E., Simberloff, D., Bacher, S., Blackburn, T.M., Carlton, J.T., Dawson, W., Essl, F., Foxcroft, L.C., Genovesi, P. and Jeschke, J.M. (2020). Scientists' warning on invasive alien species. *Biological Reviews* **95(6)**: 1511-1534.
20. Rai, P.K. (2016). Biodiversity of roadside plants and their response to air pollution in an Indo-Burma hotspot region: Implications for urban ecosystem restoration. *Journal of Asia-Pacific Biodiversity* **9(1)**: 47-55.
21. Rai, P.K. and Singh, J.S. (2020). Invasive alien plant species: Their impact on environment, ecosystem services and human health. *Ecological Indicators* **111**: 106020.
22. Rai, P.K. and Vanlalruati. (2022). Societal perception on environmental and socio-economic implications of *Tithonia diversifolia* (Hemsl.) A. Gray invasion in an Indo-Burma biodiversity hotspot. *Environmental & Socio-Economic Studies* **10(3)**: 59-66.
23. Roy, H.E., Rabitsch, W., Scalera, R., Stewart, A., Gallardo, B., Genovesi, P., Essl, F., Adriaens, T., Bacher, S., Booy, O. and Branquart, E. (2018). Developing a framework of minimum standards for the risk assessment of alien species. *Journal of Applied Ecology* **55(2)**: 526-538.
24. Seebens, H., Blackburn, T.M., Dyer, E.E., Genovesi, P., Hulme, P.E., Jeschke, J.M., Pagad, S., Pyšek, P., Winter, M., Arianoutsou, M. and Bacher, S. (2017). No saturation in the accumulation of alien species worldwide. *Nature Communications* **8(1)**: 14435.
25. Singh, A.K. (2021). Allelopathic effects of *Ageratum conyzoides* L. on seed germination and growth of pea varieties. *International Journal of Biological Innovations* **3**: 194-98.
26. Sooraj, N.P., Jaishanker, R., Sajeev, C.R., Kumar, V.S., Lijimol, D. and Ammini, J. (2020). Influence of forest canopy gaps on establishment of *Mikania micrantha* kunth, an invasive plant, in a tropical forest in Southern Western Ghats, India. *Applied Ecology and Environmental Sciences* **8(5)**: 199-206.
27. Sun, Y., Zhang, X., Wang, S., Wu, X., Wang, Y., Wang, X., Li, J., Liang, Z., Luo, T., Yu, Y. and Wu, Y. (2022). Phenotypic plasticity couples with transcriptomic flexibility in *Leymus chinensis* under diverse edaphic conditions. *Environmental and Experimental Botany* **197**: 104838.
28. Swain, T. and Hillis, W.E. (1959). The phenolic constituents of *Prunus domestica*. I. The quantitative analysis of phenolic constituents. *Journal of the Science of Food and Agriculture* **10(1)**: 63-68.
29. Syngkli, R.B., Lallianpuii, S. and Rai, P.K. (2022). Microcosm investigation on the allelochemical potential of *Ageratum conyzoides* to the selected food crop. *Ecology, Environment* and *Conservation* **28**: 298-304.
30. Tang, X., Huang, W., Wang, L. and Luo, K. (2023). Effects of growth irradiance on growth, chlorophyll fluorescence and photosynthesis parameters of *Gardenia jasminoides* J. Ellis. *Biologia* **78**: 2679–2687.
31. Umesha, S., Manukumar, H.M. and Chandrasekhar, B. (2018). Sustainable agriculture and food security. In *Biotechnology for Sustainable Agriculture*, pp. 67-92. Woodhead Publishing, an imprint of Elsevier.
32. Weidenhamer, J.D., Cipollini, D., Morris, K., Gurusinghe, S. and Weston, L.A. (2023). Ecological realism and rigour in the study of plant-plant allelopathic interactions. *Plant and Soil* **489(1)**: 1-39.
33. Yuan, L., Li, J.M., Yu, F.H., Oduor, A.M. and van Kleunen, M. (2021). Allelopathic and competitive interactions between native and alien plants. *Biological Invasions* **23(10)**: 3077-3090.
34. Zimdahl, R. L. (2018). Allelopathy. In: *Fundamentals of Weed Science.* 5th edition, pp. 253-270. Academic Press, New York.