ALLELOPATHIC POTENTIAL OF *LANTANA CAMARA* AGAINST SELECTED WEEDS OF WHEAT CROP

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Abstract. The current study was aimed at screening allelopathic potential of *Lantana camara* L. against some noxious weeds (i.e. *Phalaris minor, Avena fatua, Chenopodium album, Euphorbia helioscopia* and *Rumex dentatus*) of wheat crop. The screening test of these weeds was carried out in laboratory on filter paper, soil and agar by three solvent extracts (viz., aqueous, hexane and methanolic) and sandwich method. The methanolic *L. camara* extract significantly suppressed germination percentage of *E. helioscopia*, *P. minor R. dentatus* and *A. fatua* measuring at 65%, 63%, 61% and 60%, respectively. Likewise, *L. camara* significantly suppressed radical length of *A. fatua*, *P. minor and C. album* with 54%, 53% and 52%, respectively compared to the control. Besides, plumule length of *E. helioscopia*, *C. album*, *R. dentatus* and *A. fatua* was also inhibited at 56%, 55%, 53% and 53%, respectively by *L. camara* methanolic extract. It can be concluded that *L. camara* methanolic extract significantly reduced seed germination, radical and plumule length of selected weeds and have potential to be used in further detailed evaluation for searching bioherbicide from this plant.
Keywords: *allelopathic activity, bio-herbicide, filter paper, noxious weed, sandwich method, screening test, wheat*

Introduction

Wheat (*Triticum aestivum* L.) that belongs to family Poaceae, is one of the most important cereal crops of the world. It provides human nutrition to the most of human populations. Weeds are growing in cultivated crops and compete for light, moisture, other vital elements of nutrition and space and cause low quality and less productivity with raised costs of production (Arafat et al., 2015). Controlling weeds through traditional methods is time consuming with more labor cost. While weed control through synthetic chemicals, is expensive and hazardous that also cause environmental pollution (Dallali et al., 2017). This situation necessitates developing alternate weed management strategies (Thi et al., 2008). Certain plants produce many chemicals which are released by certain processes like, exudation, leaching and

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decomposition, etc. These chemicals can be obtained from different parts of certain plants like, flower, roots, stem and leaves. Such chemicals become a source of allelopathy, commonly called as allelochemicals. Allelopathy is a form of plant interference that can significantly influence ecosystem and agro ecosystem dynamics (Michelangelo et al., 2016). Allelochemicals come from the class of secondary metabolites. These are produced as byproducts in the primary metabolic ways of the plants (Anwar et al., 2013). Like many other natural compounds, these chemicals have the capacity of producing wide array of biological effects and can be quite useful for weed control processes as well as agriculture systems (Zhou et al., 2004).

Lantana camara L. belongs to Verbenaceae family. This plant possessed certain aromatic compounds which can inhibit early growth and seed germination of adjacent plant by outcompeting for soil nutrients and fluctuating micro environment by producing dense thickets (Dobhal et al., 2010). Keeping this in view, this study was undertaken for evaluating allelopathic activity of *L. camara* against some major weeds (viz., *Phalaris minor, Avena fatua, Chenopodium album, Euphorbia helioscopia* and *Rumex dentatus*) of wheat crop.

Materials and methods

Collection and mechanical processing of L. camara

This research was carried out at Plant Physiology Laboratory, Department of Botany, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi (PMAS-AAUR), Pakistan. The mature leaves of *L. camara* were collected from district Rawalpindi (73° 02' E longitude and 33° 36' N latitude, 508 m above sea level), Punjab, Pakistan and washed for several times under running tap water to remove dust. The same leaves were dried in blotting paper for 4 weeks in shade at room temperature (20-25 °C). The dried leaves were crushed using heavy duty blender (warring Lab.), to make fine powder, passed through mesh size 2 mm and kept in air tight plastic zip lock bags separately at 4 °C (Anwar et al., 2013).

Procurement and surface sterilization of test species seeds

Seeds of some noxious weeds sensitive to herbicide (Shahid et al., 2006) such as *Avena fatua, Chenopodium album, Euphorbia helioscopia*, *Phalaris minor* and *Rumex dentatus* and wheat (Wafaq-2001) were procured from the Barani Agricultural Research Institute (BARI), Chakwal (72.7211° E longitude and 32.9309° N latitude), District Rawalpindi, Punjab, Pakistan. These weeds are reported to be the most densely populated weeds of wheat crop (Qureshi and Bhatti, 2001; Qureshi et al., 2009). Seeds were surface sterilized with 2% (w/v) solution of Sodium hypochlorite (NaOCl) for 5-8 min. After disinfection, the seeds were washed several times with distilled water (Anwar et al., 2016).

Studied parameters

Subsequent three growth parameters were used for screening allelopathic potential as follows:

a. Germination percentage
b. Radical length (cm)
c. Plumule length (cm)

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Aqueous extract preparation

An aliquot (10 g) of dried leaf powder of *L. camara* was soaked in 100 ml distilled water in a flask and agitated at room temperature (20-25 °C) for 24 h on an orbital shaker (160 rpm). The extract was strained through muslin cloth and finally filtered through Whatman filter paper No. 1. Aqueous extract was obtained as filtrate of the mixture and final volume was attuned to 100 ml, this gives 10% water extract (Maharjan et al., 2007). This stock solution was then diluted with distilled water to prepare the different concentration of the extract i.e. T_1 (100%), T_2 (75%), T_3 (50%) after Sahu and Devkota (2013). The control was distilled water (0%), indicated as T_4. The extract was stored at 4 °C in pre-disinfected flasks. To evade adulteration and forthcoming chemical modifications, the extracts were ensured to be used within 3-4 days (Anwar et al., 2017a).

Hexane extract preparation

An aliquot (10 g) of dried leaf powder of *L. camara* was mixed with hexane (0.5 L) repeated three times for 6 h on shaker. This extract was filtered, concentrated and dried over a rotary evaporator in pre-weighed flask. The obtained residue was 6.14 g. The stock solution was then diluted with hexane to prepare three concentrations i.e. T_1 (100%), T_2 (75%), T_3 (50%) and T_4 (0% control). These stored at 4 °C in pre-sterilized flasks (Sahu and Devkota, 2013).

Methanolic extract preparation

An aliquot (10 g) of dried leaf powder of *L. camara* placed on shaker with methanol (to extract polar compounds) (0.5 L) repeated three time for 6 h on shaker. This extract was filtered, concentrated, and dried over a rotary evaporator in pre-weighed flask. The obtained residue was 25.29 g. The stock solution was than diluted with methanol to prepare three concentrations i.e. T_1 (100%), T_2 (75%), T_3 (50%) and T_4 (0% control). These stored at 4 °C in pre-sterilized flasks (Sahu and Devkota, 2013).

Bioassay techniques

An aliquot (15 ml) of *L. camara* extract added on 25 g soil per Petri dish and 5 ml extract was added on filter paper per Petri dish while distilled water, hexane and methanol used as control in aqueous, hexane and methanolic extraction respectively. Ten seeds of selected test species were used per Petri dish. Each treatment was replicated for five times. The Petri dishes were wrapped with squash tape, enclosed with Aluminum foil and incubated in the growth chamber (NTS Model MI-25S) at room temperature (20-25 °C) for 15 days. The germination percentages, lengths of radical and plumule were calculated of each test species by comparing with control (Khan et al., 2008).

Sandwich method

The sandwich method was followed after Fujii et al. (2003, 2004). Five ml of 0.75% (w/v) agar (Nalge Nunc Intl., Roskilde, Denmark, gelling temperature 30-31 °C) was poured in each of the six-well (10 cm^2 area /well) into multi-dish plastic plate. The agar solution was left for solidification. *L. camara* leaf powder @ 10 and 50 mg were placed in wells of the plate and were roofed by a thin layer of 0.75% (w/v) agar. After solidification, 10 seeds of each test species were placed on agar gel in each well of the plate. The multi-well plastic plates were then wrapped with the plastic tape and incubated

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in the growth chamber (NTS Model MI-25S) at room temperature (20-25 °C) for 15 days. In the control treatment, only agar gel without dried leaves powder was used as a seed bed for test species seeds. Each treatment was replicated five times. The germination percentages, lengths of radical and plumule for each test species were calculated by comparing with control. An aliquot (10 mg) of dried leaf powder of *L. camara* added on filter paper along with 5 ml distilled water per Petri dish while an aliquot (50 mg) of dried leaf powder of *L. camara* added on 25 g soil along with 15 ml distilled water per Petri dish (Raana et al., 2012). Ten surface sterilized seeds of test species were placed to each sterilized Petri plate. The Petri dishes were wrapped with squash tape, enclosed with Aluminium foil and incubated in the growth chamber (NTS Model MI-25S) at room temperature (20-25 °C) for 15 days. The germination percentages, lengths of radical and plumule were calculated of each test species by comparing with control (Anwar et al., 2017b).

Statistical analysis

A completely randomized design (CRD) with five replications was used for the experiments. The statistical analysis was completed by STATISTIX 9 and means were separated by using Fisher's protected LSD test (Nekonam et al., 2014).

Results

Allelopathic potential of L. camara aqueous extract

Germination percentage

The results revealed that *L. camara* aqueous extract significantly inhibited germination percentage of *R. dentatus* (58%), followed by *E. helioscopia* (56%), *A. fatua* (57%) and *P. minor* (55%) on filter paper, whereas, no significant effect on germination percentage of *T. aestivum* and *C. album* (*Table 1*). The aqueous extract on soil significantly inhibited seed germination of *E. helioscopia* (64%), followed by *P. minor* (63%), *R.* dentatus (61%) and *A. fatua* (60%) as compared to control (*Table 2*). The results further indicated that maximum (96% germination was observed for *T. aestivum* and *C. album* (*Table 1*). Besides, minimum germination was noted for *R. dentatus* (42%) and *E. helioscopia* (36%) on filter paper and soil, respectively (*Tables 1* and *2*). The statistics also recommended that germination percentage reduction of the *R. dentatus, E. helioscopia, A. fatua* and *P. minor* was concentration dependent (*Fig. 1a*).

Table 1. *Allelopathic effect of L. camara aqueous extract (AE) on germination percentage of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ AE}$	86^{a}	38^{d}	36^{d}	37^{d}	39^{d}	76^{a}
$T_{2\ AE}$	88^{a}	62^{c}	55c	56^{c}	59^{c}	78^{a}
$T_{3\ AE}$	89^{a}	76^{b}	71^{b}	68^{b}	75^{b}	79^{a}
$T_{4\ AE}$	90^{a}	89^{a}	86^{a}	82^{a}	88^{a}	80^{a}
LSD	17.902	29.46	18.32	19.23	17.957	21.13
F-value	12.13*	18.29*	14.85*	31.44*	31.00*	17.61*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

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Table 2. *Allelopathic effect of L. camara aqueous extract (AE) on germination percentage of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ AE}$	87^{a}	36^{d}	34^{d}	31^{d}	32^{d}	77^{a}
$T_{2\ AE}$	89^{a}	52^{c}	52^{c}	49^{c}	51^{c}	79^{a}
$T_{3\ AE}$	90^{a}	71^{b}	69^{b}	60^{b}	69^{b}	80^{a}
$T_{4\ AE}$	91^{a}	90^{a}	87^{a}	83^{a}	89^{a}	81^{a}
LSD	18.608	14.197	19.778	17.604	14.541	18.12
F-value	10.89**	42*	13.52*	14.67*	43.98*	14.65*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

Radical length

The data revealed that the highest radical length inhibition activity was exhibited by *A. fatua* (52%), *P. minor* (51%) and *C. album* (49%) in *L. camara* aqueous extract on filter paper. The results further indicated that extract on soil caused significant radical length reduction of *A. fatua* (54%), *P. minor* (53%) and *C. album* (52%) as compared to control. While the radical length of *T. aestivum, R. dentatus* and *E. helioscopia* remained unaffected. The results also illustrated that minimum radical length was noted for *A. fatua* i.e. 48% and 46% on filter paper and soil, respectively (*Tables 3* and *4*). The maximum radical length (97%) was noted for *T. aestivum, R. dentatus* and *E. helioscopia* (*Fig. 1b*).

Plumule length

The data obtained exhibited that the aqueous extract of *L. camara* significantly inhibited the plumule length of *E. helioscopia* (52%), *A. fatua* (50%), *R. dentatus* (50%) and *C. album* (50%) as compared to control on filter paper. There was no significant effect on plumule elongation of *T. aestivum and P. minor*. Likewise, *L. camara* aqueous extract significantly inhibited plumule length of *E. helioscopia* (56%), *C. album* (55%), *R. dentatus* (53%) and *A. fatua* (53%) in soil. The statistical data concluded that minimum plumule length was noted for *E. helioscopia* i.e. 48% and 44% on filter paper and soil, respectively (*Tables 5* and *6*). The statistical figures also proposed that maximum plumule length (96%) was noted for *T. aestivum and P. minor* (*Fig. 1c*).

Table 3. *Allelopathic effect of L. camara aqueous extract (AE) on radical length (cm) of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ AE}$	9.01^{a}	4.46^{d}	8.11^{a}	4.62^{d}	7.15^{a}	4.10^{d}
$T_{2\ AE}$	9.05^{a}	6.71^{c}	8.16^{a}	6.45^{c}	7.19^{a}	5.52^{c}
$T_{3\ AE}$	9.05^{a}	8.02^{b}	8.19^{a}	7.92^{b}	7.22^{a}	6.78^{b}
$T_{4\ AE}$	9.11^{a}	9.25^{a}	8.21^{a}	9.42^{a}	7.28^{a}	8.11^{a}
LSD	1.7087	3.0879	1.0971	0.6573	1.0360	1.0027
F-value	47.38*	18.78*	126.95*	309.12*	128.48*	92.48*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

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Table 4. *Allelopathic effect of L. camara aqueous extract (AE) on radical length (cm) of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ AE}$	9.14^{a}	4.31^{d}	8.12^{a}	4.52^{d}	7.19^{a}	4.01^{c}
$T_{2\ AE}$	9.19^{a}	5.02^{c}	8.27^{a}	5.65^{b}	7.33^{a}	4.09^{c}
$T_{3\ AE}$	9.21^{a}	7.06^{b}	8.31^{a}	6.29^{b}	7.43^{a}	5.99^{b}
$T_{4\ AE}$	9.25^{a}	9.34^{a}	8.43^{a}	9.65^{a}	7.49^{a}	8.37^{a}
LSD	3.9879	1.8106	1.1918	1.0912	1.0634	0.8063
F-value	19.78*	52.46*	98.97*	83.01*	74.89*	126.70*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

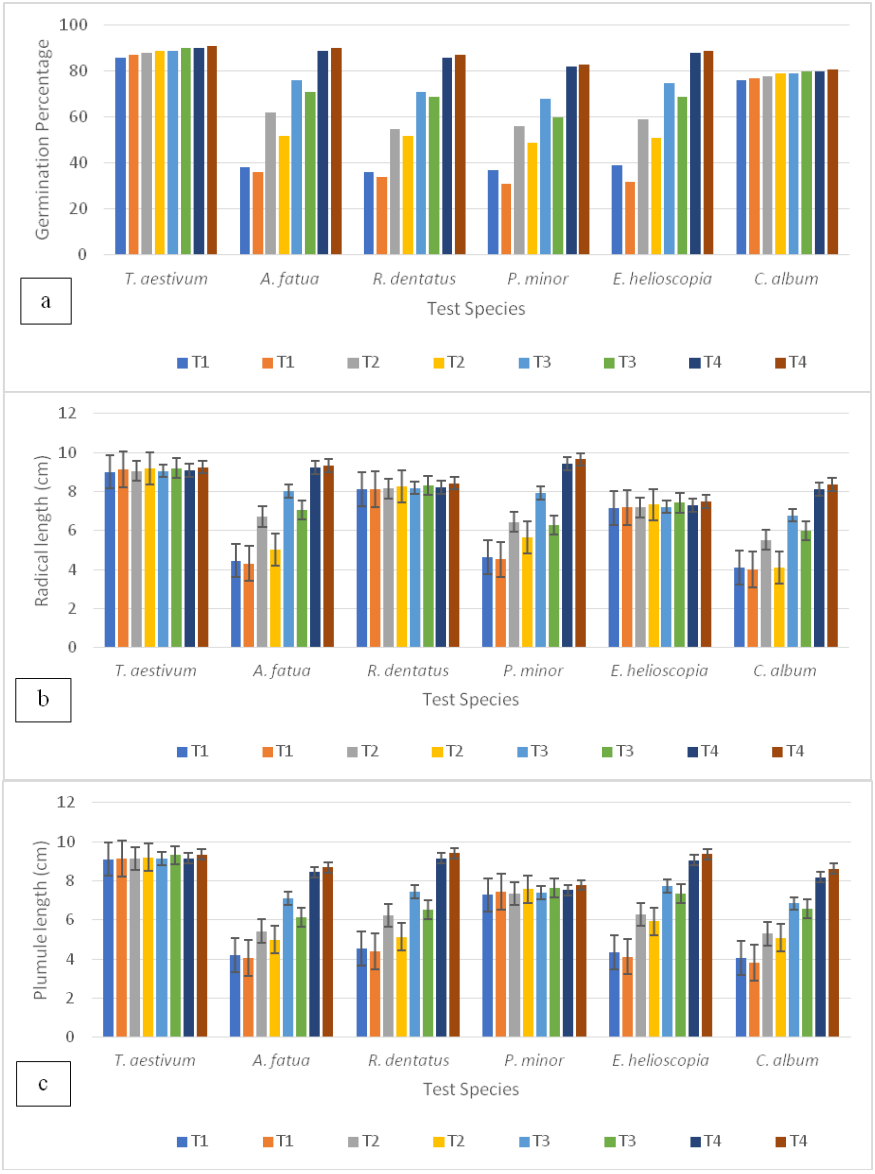

Figure 1. *Allelopathic potential of L. camara aqueous extract against test species on filter paper (FP) and soil (S) on: (a) germination percentage, (b) radical length, (c) plumule length*

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Table 5. *Allelopathic effect of L. camara aqueous extract (AE) on plumule length (cm) of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ AE}$	9.11^{a}	4.20^{d}	4.53^{d}	7.28^{a}	4.33^{d}	4.06^{d}
$T_{2\ AE}$	9.13^{a}	5.43^{c}	6.24^{c}	7.33^{a}	6.28^{c}	5.29^{c}
$T_{3\ AE}$	9.15^{a}	7.09^{b}	7.46^{b}	7.41^{a}	7.73^{b}	6.84^{b}
$T_{4\ AE}$	9.16^{a}	8.45^{a}	9.15^{a}	7.53^{a}	9.06^{a}	8.19^{a}
LSD	1.3210	0.6647	1.0678	0.9468	0.6294	2.9953
F-value	45.63*	238.96*	97.24*	37.04*	197.36*	13.53*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

Table 6. *Allelopathic effect of L. camara aqueous extract (AE) on plumule length (cm) of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ AE}$	9.13^{a}	4.06^{c}	4.38^{c}	7.43^{a}	4.12^{d}	3.81^{d}
$T_{2\ AE}$	9.21^{a}	4.98^{c}	5.12^{c}	7.58^{a}	5.92^{c}	5.09^{c}
$T_{3\ AE}$	9.32^{a}	6.14^{b}	6.52^{b}	7.64^{a}	7.34^{b}	6.58^{b}
$T_{4\ AE}$	9.34^{a}	8.68^{a}	9.41^{a}	7.78^{a}	9.37^{a}	8.62^{a}
LSD	2.9853	1.2127	0.6756	0.6851	0.8319	0.7647
F-value	12.53*	70.45*	117.35*	245.78*	209.87*	237.96*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

Allelopathic potential of L. camara hexane extract

Germination percentage

There was significant reduction of germination of *E. helioscopia* (35%), followed by *P. minor* (33%) and *A. fatua* (32%) on filter paper (*Table 7*), whereas, no significant effect on the germination of *T. aestivum, R. dentatus* and *C. album*, showing resistance to the extract. The data illustrated that the highest seed germination inhibition was noted for *P. minor* (40%), followed by *A. fatua* (39%) and *E. helioscopia* (38%) by the incorporation of *L. camara* hexane extract into soil. The maximum (97%) germination noted for *T. aestivum, R. dentatus* and *C. album*. In the present study, minimum germination was noted for *E. helioscopia* (65%) and *P. minor* (60%) on filter paper and soil, respectively (*Tables 7* and *8*). The statistics also recommended that allelopathic inhibitory effect was concentration dependent for *E. helioscopia*, *P. minor* and *A. fatua* with concentration increase, suppression potential was gradually enhanced (*Fig. 2a*).

Radical length

The experimental results of the current study indicated that the highest radical length inhibition activity was exhibited by *A. fatua* (38%) and *R. dentatus* (34%) in *L. camara* hexane extract on filter paper. statistical data concluded that hexane extract on soil

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caused significant radical length reduction of *A. fatua* (40%) and *R. dentatus* (39%) as compared to control. The statistics also recommended that radical length of *T. aestivum, P. minor, E. helioscopia* and *C. album* remained unaffected. The results also illustrated that minimum radical length was noted for *A. fatua* i.e. 62% and 66% on filter paper and soil, respectively (*Tables 9* and *10*). The maximum radical length (96%) was noted for *T. T. aestivum, P. minor, E. helioscopia* and *C. album* (*Fig. 2b*).

Table 7. *Allelopathic effect of L. camara hexane extract (HE) on germination percentage of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ HE}$	86^{a}	63^{c}	82^{a}	55^{c}	60^{c}	76^{a}
$T_{2\ HE}$	88^{a}	71^{c}	83^{a}	59^{c}	67^{c}	78^{a}
$T_{3\ HE}$	89^{a}	82^{b}	84^{a}	71^{b}	80^{b}	79^{a}
$T_{4\ HE}$	90^{a}	93^{a}	85^{a}	82^{a}	92^{a}	80^{a}
LSD	19.708	18.890	17.67	19.60	17.435	29.778
F-value	11.89**	17.19*	32.71*	31.19*	21.97*	23.52*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

Table 8. *Allelopathic effect of L. camara hexane extract (HE) on germination percentage of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ HE}$	89^{a}	58^{d}	84^{a}	50^{c}	58^{c}	78^{a}
$T_{2\ HE}$	90^{a}	68^{c}	85^{a}	58^{c}	64^{c}	80^{a}
$T_{3\ HE}$	91^{a}	80^{b}	86^{a}	68^{b}	74^{b}	81^{a}
$T_{4\ HE}$	92^{a}	95^{a}	87^{a}	84^{a}	94^{a}	82^{a}
LSD	13.554	17.510	16.580	14.744	14.08	19.13
F-value	13.63*	22.36*	51.38*	21.04*	38.81*	31.14*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Table 9. *Allelopathic effect of L. camara hexane extract (HE) on radical length (cm) of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ HE}$	8.08^{a}	5.63^{d}	5.41^{c}	7.14^{a}	7.06^{a}	8.12^{a}
$T_{2\ HE}$	8.11^{a}	6.78^{c}	6.01^{c}	7.17^{a}	7.08^{a}	8.29^{a}
$T_{3\ HE}$	8.15^{a}	7.89^{b}	7.11^{b}	7.19^{a}	7.10^{a}	8.31^{a}
$T_{4\ HE}$	8.18^{a}	9.04^{a}	8.15^{a}	7.22^{a}	7.11^{a}	8.33^{a}
LSD	2.3332	1.4291	0.8679	1.2428	0.7319	0.8297
F-value	27.95*	23.83*	81.03*	29.85*	219.87*	222.41*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

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Table 10. *Allelopathic effect of L. camara hexane extract (HE) on radical length (cm) of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ HE}$	8.13[a]	5.54[c]	5.01[c]	7.13[a]	7.12[a]	8.22[a]
$T_{2\ HE}$	8.19[a]	6.48[c]	5.89[c]	7.26[a]	7.14[a]	8.39[a]
$T_{3\ HE}$	8.23[a]	7.61[b]	6.99[b]	7.31[a]	7.17[a]	8.41[a]
$T_{4\ HE}$	8.28[a]	9.24[a]	8.25[a]	7.32[a]	7.21[a]	8.43[a]
LSD	2.4502	0.9978	0.7720	1.1434	0.8468	1.1019
F-value	9.54**	72.85*	102.44*	72.9*	36.04*	86.41*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

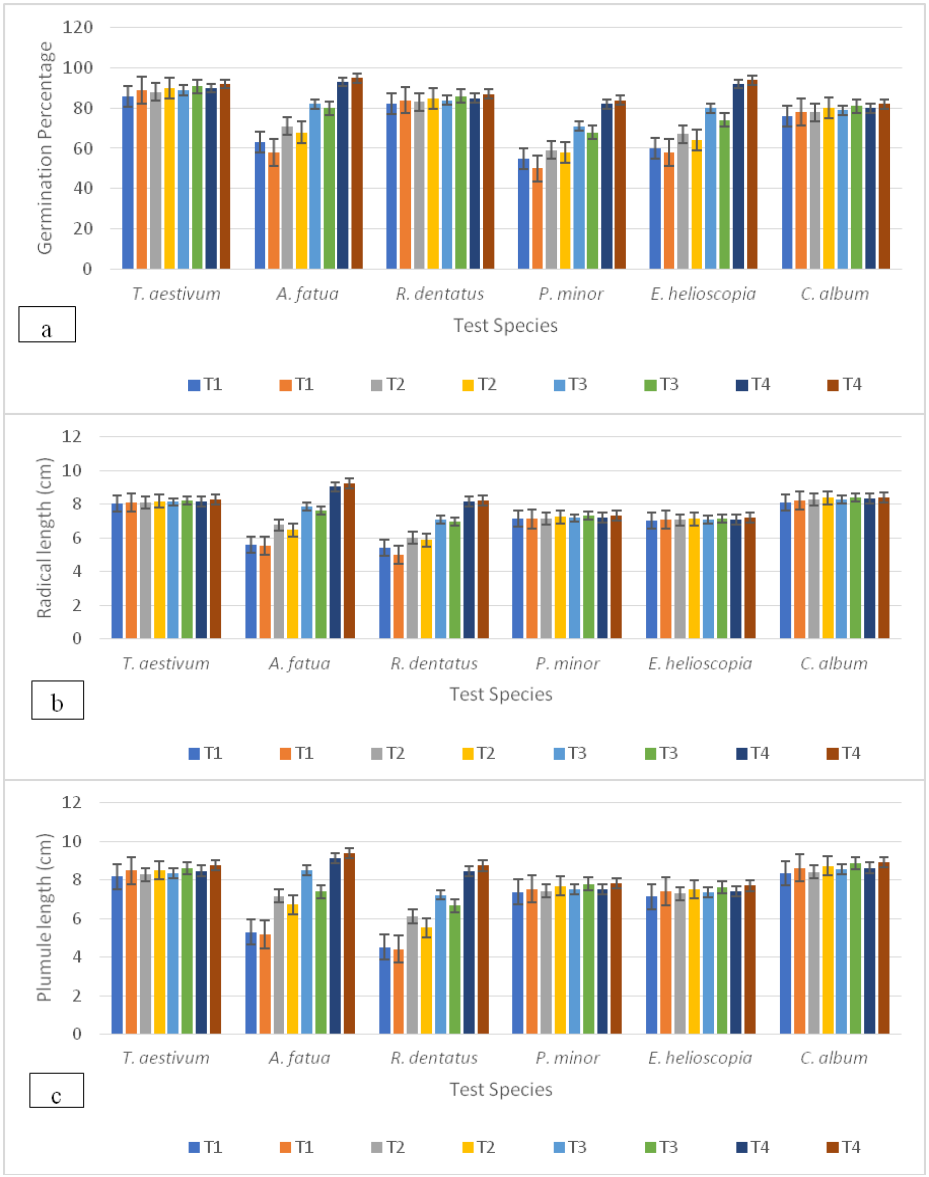

Figure 2. *Allelopathic potential of L. camara hexane extract against test species on filter paper (FP) and soil (S) on: (a) germination percentage (b) radical length (c) plumule length.*

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Plumule length

Analysis of the data revealed that *L. camara* hexane extract significantly inhibited the plumule length of *R. dentatus* (46%) and *A. fatua* (42%) as compared to control on filter paper. Interestingly, there was no significant effect on plumule elongation of *T. aestivum, P. minor, E. helioscopia* and *C. album*. Likewise, *L. camara* hexane extract significantly inhibited plumule length of *R. dentatus* (49%) and *A. fatua* (45%) in soil. The statistical data concluded that minimum plumule length was noted for *R. dentatus* i.e., 54% and 51% on filter paper and soil, respectively (*Tables 11* and *12*). The statistical figures also proposed that maximum plumule length (95%) was noted for *T. aestivum, P. minor, E. helioscopia* and *C. album* (*Fig. 2c*).

Table 11. *Allelopathic effect of L. camara hexane extract (HE) on plumule length (cm) of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ HE}$	8.18^{a}	5.31^{d}	4.53^{d}	7.39^{a}	7.14^{a}	8.34^{a}
$T_{2\ HE}$	8.29^{a}	7.18^{c}	6.12^{c}	7.43^{a}	7.29^{a}	8.43^{a}
$T_{3\ HE}$	8.35^{a}	8.51^{b}	7.23^{b}	7.51^{a}	7.35^{a}	8.55^{a}
$T_{4\ HE}$	8.48^{a}	9.14^{a}	8.45^{a}	7.52^{a}	7.41^{a}	8.63^{a}
LSD	2.1332	1.5092	0.6679	1.5428	0.7497	0.6297
F-value	28.55*	24.81*	84.03*	27.95*	220.41*	221.91*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Table 12. *Allelopathic effect of L. camara hexane extract (HE) on plumule length (cm) of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ HE}$	8.49^{a}	5.18^{c}	4.42^{d}	7.54^{a}	7.43^{a}	8.64^{a}
$T_{2\ HE}$	8.51^{a}	6.72^{b}	5.53^{c}	7.69^{a}	7.52^{a}	8.73^{a}
$T_{3\ HE}$	8.62^{a}	7.41^{b}	6.67^{b}	7.79^{a}	7.62^{a}	8.88^{a}
$T_{4\ HE}$	8.78^{a}	9.39^{a}	8.75^{a}	7.82^{a}	7.71^{a}	8.93^{a}
LSD	2.3501	0.8878	0.7630	1.6434	1.3019	0.5319
F-value	9.65**	75.85*	101.54*	73.1*	84.41*	239.87*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Allelopathic potential of L. camara methanolic extract

Germination percentage

The statistical data exposed that *L. camara* methanolic extract significantly inhibited germination of *R. dentatus* (68%), *A. fatua* (66%), *E. helioscopia* (63%) and *P. minor* (62%) on filter paper, whereas, no significant effect on germination of *T. aestivum* and *C. album* showing resistance against extract. Similarly, *L. camara* methanolic extract on soil significantly suppressed seed germination of *A. fatua* (76%), *E. helioscopia* (73%),

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R. dentatus (70%) and *P. minor* (69%). It was noted that maximum (95%) germination was observed for *T. aestivum* and *C. album*. In the present study, it was recognized that minimum germination was noted for *R. dentatus* (32%) followed by *A. fatua* (24%) on filter paper and soil, respectively (*Tables 13* and *14*). The results revealed that germination reduction of the *R. dentatus*, *A. fatua*, *E. helioscopia* and *P. minor* were concentration dependent (*Fig. 3a*).

Table 13. *Allelopathic effect of L. camara methanolic extract (ME) on germination percentage of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ ME}$	88^{a}	31^{d}	28^{d}	32^{d}	33^{d}	78^{a}
$T_{2\ ME}$	90^{a}	56^{c}	58^{c}	54^{c}	51^{c}	80^{a}
$T_{3\ ME}$	91^{a}	75^{b}	74^{b}	69^{b}	70^{b}	81^{a}
$T_{4\ ME}$	92^{a}	91^{a}	88^{a}	84^{a}	90^{a}	82^{a}
LSD	18.65	18.702	15.197	39.778	18.604	16.541
F-value	15.19*	13.13*	42.98*	33.52*	16.67*	45.98*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Table 14. *Allelopathic effect of L. camara methanolic extract (ME) on germination percentage of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ ME}$	90^{a}	22^{d}	27^{d}	26^{d}	25^{d}	79^{a}
$T_{2\ ME}$	91^{a}	49^{c}	48^{c}	42^{c}	47^{c}	81^{a}
$T_{3\ ME}$	92^{a}	69^{b}	68^{b}	61^{b}	62^{b}	82^{a}
$T_{4\ ME}$	93^{a}	92^{a}	89^{a}	85^{a}	91^{a}	83^{a}
LSD	11.554	17.857	15.18	14.944	16.480	15.61
F-value	13.83*	31.80*	38.99*	21.14*	51.28*	25.18*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Radical length

The results obtained in the study indicated that *L. camara* methanolic extract significantly inhibited radical length of *C. album* (60%), *P. minor* (63%) and *A. fatua* (66%) on filter paper, whereas, no significant effect was noted for *T. aestivum*, *R. dentatus* and *E. helioscopia* showing resistance against extract. Similarly, the applications of extract into soil significantly suppressed radical length of *A. fatua* (68%), *P. minor* (66%) *C. album* (63%) and *E. helioscopia* (55%) as compared to control (*Tables 15* and *16*). The maximum (96%) radical length was observed for *T. aestivum* and *R. dentatus.* The final data concluded that minimum radical length was noted for *C. album (*40%) and *A. fatua* (32%) on filter paper and soil, respectively (*Fig. 3b*).

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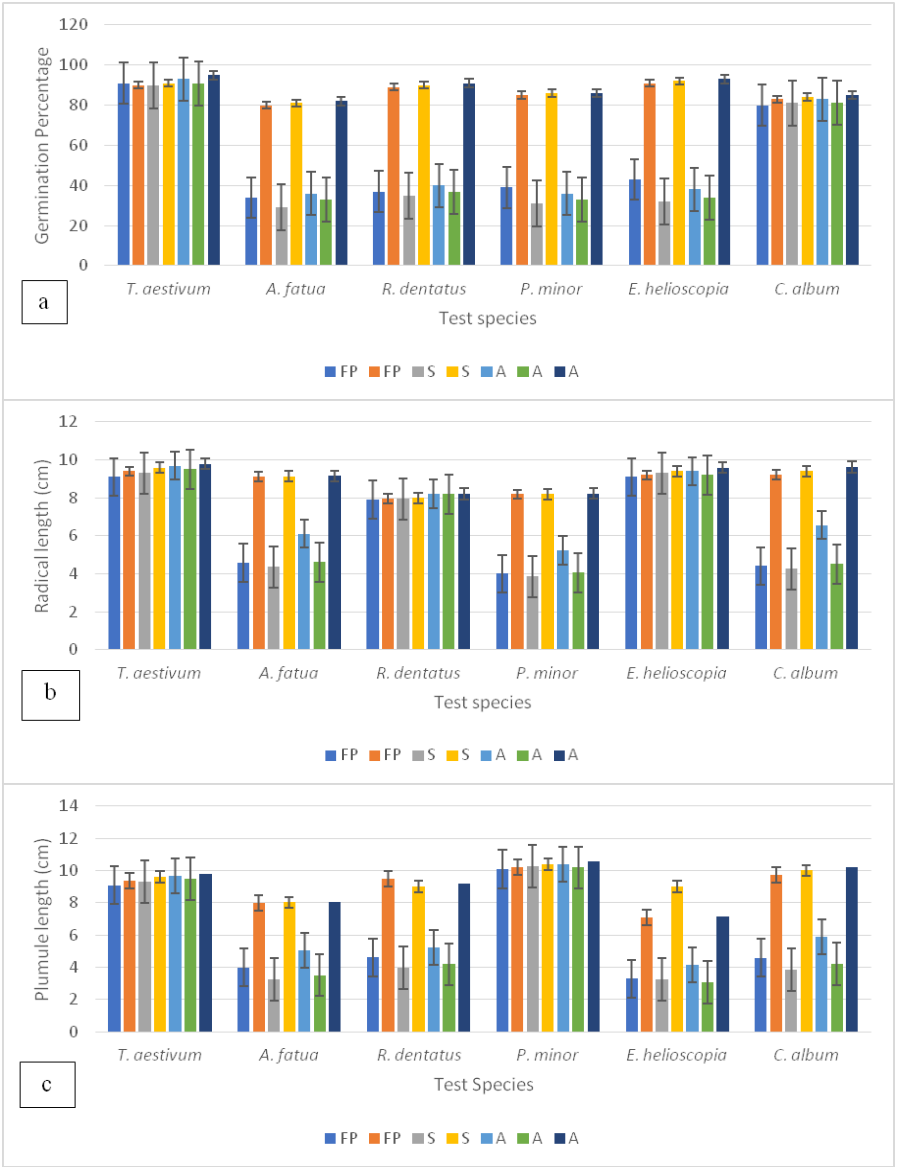

Figure 3. *Allelopathic potential of L. camara leaf powder against test species on filter paper (FP), soil (S) and agar (A) on: (a) germination percentage (b) r*adical length (c) plumule *length*

Table 15. *Allelopathic effect of L. camara methanolic extract (ME) on radical length (cm) of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ ME}$	9.11^{a}	3.18^{d}	8.31^{a}	3.59^{d}	7.49^{a}	3.39^{d}
$T_{2\ ME}$	9.23^{a}	6.24^{c}	8.43^{a}	6.88^{c}	7.51^{a}	5.46^{c}
$T_{3\ ME}$	9.37^{a}	7.93^{b}	8.54^{a}	8.10^{b}	7.63^{a}	7.11^{b}
$T_{4\ ME}$	9.43^{a}	9.49^{a}	8.67^{a}	9.81^{a}	7.69^{a}	8.58^{a}
LSD	3.7879	2.5542	0.8095	1.2569	1.9073	0.9043
F-value	16.78*	23.58*	206.09*	39.32*	27.90*	20.88*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

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Table 16. *Allelopathic effect of L. camara methanolic extract (ME) on radical length (cm) of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ ME}$	9.46[a]	3.07[c]	8.52[a]	3.35[d]	3.51[a]	3.31[d]
$T_{2\ ME}$	9.51[a]	5.45[b]	8.66[a]	5.28[c]	7.65[a]	4.49[c]
$T_{3\ ME}$	9.61[a]	6.03[b]	8.77[a]	7.31[b]	7.72[a]	6.45[b]
$T_{4\ ME}$	9.65[a]	9.56[a]	8.89[a]	9.99[a]	7.87[a]	8.85[a]
LSD	2.4770	1.740	0.989	1.3125	1.2662	2.420
F-value	18.01*	44.47*	64.33*	121.84*	94.32*	53.72*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Plumule length

The data obtained exhibited that *L. camara* methanolic extract significantly suppressed the plumule length of *R. dentatus* (63%), *A. fatua* (63%), *C. album* (61%) and *E. helioscopia* (59%) as compared control on filter paper. Interestingly, there was no significant effect on plumule elongation of *T. aestivum and P. minor*. Likewise, *L. camara* methanolic extract significantly inhibited plumule length of *E. helioscopia* (67%), *R. dentatus* (66%), *A. fatua* (65%) and *C. album* (64%) in soil. The statistical data concluded that minimum plumule length was noted for *R. dentatus* (37%) and *E. helioscopia* (33%) on filter paper and soil, respectively (*Tables 17* and *18*). The statistical figures also proposed that maximum plumule length (96%) was noted for *T. aestivum and P. minor* (*Fig. 3c*).

Allelopathic potential of L. camara leaf powder

Germination percentage

The data revealed that *A. fatua* (60%), *R. dentatus* (58%), *P. minor* (54%) and *E. helioscopia* (53%) possessed significant germination in *L. camara* leaf powder on filter paper, whereas, no significant effect on germination of *T. aestivum* and *C. album* showing resistance to dry powder. It is also clear from the result that *E. helioscopia* (65%), *P. minor* (64%), *A. fatua* (64%) and *R. dentatus* (61%) showed inhibition respectively as compared to control in powder applied into soil. The results also declared that maximum (95%) germination was noted for *T. aestivum* and *C. album.* In the present study, it was demonstrated that minimum germination was noted for *A. fatua* (42%) and *E. helioscopia* (45%) on filter paper and soil, respectively. The experimental results of the current study indicated on agar the highest germination reduction was noted for *E. helioscopia* (59%), followed by *P. minor* (58%), *R. dentatus* (56%) and *A. fatua* (56%) at 10 mg conc. Similarly, the highest germination reduction was noted for *E. helioscopia* (63%), followed by *P. minor* (62%), *A. fatua* (60%) and *R. dentatus* (59%) at 50 mg conc. The statistical data concluded that minimum germination was noted for *E. helioscopia* i.e. 41% and 37% at 10 mg and at 50 mg conc., respectively. The statistics also recommended that with the increase of concentration, the inhibitory effect was progressively increased for *E. helioscopia, P. minor, A. fatua* and *R. dentatus*

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(*Table 19*). The statistical results recommended that the germination %age *T. aestivum* and *C. album* were completely resistant to dry powder (*Fig. 4a*).

Table 17. *Allelopathic effect of L. camara methanolic extract (ME) on plumule length (cm) of test species on filter paper*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ ME}$	9.33^{a}	3.19^{d}	3.42^{d}	7.31^{a}	3.71^{d}	3.26^{d}
$T_{2\ ME}$	9.41^{a}	5.97^{c}	6.38^{c}	7.44^{a}	6.28^{c}	5.64^{c}
$T_{3\ ME}$	9.50^{a}	7.33^{b}	7.92^{b}	7.59^{a}	7.91^{b}	7.18^{b}
$T_{4\ ME}$	9.59^{a}	8.55^{a}	9.27^{a}	7.61^{a}	9.16^{a}	8.29^{a}
LSD	1.4210	0.6947	1.4678	0.6468	0.9294	1.6091
F-value	43.63*	228.96*	95.24*	35.04*	193.36*	25.73*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Table 18. *Allelopathic effect of L. camara methanolic extract (ME) on plumule length (cm) of test species on soil*

Treatments	Test species					
	T. aestivum	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
$T_{1\ ME}$	9.41^{a}	3.09^{d}	3.27^{d}	7.56^{a}	3.11^{d}	3.11^{d}
$T_{2\ ME}$	9.53^{a}	4.55^{c}	5.79^{c}	7.68^{a}	5.12^{c}	5.23^{c}
$T_{3\ ME}$	9.65^{a}	7.08^{b}	7.12^{b}	7.79^{a}	7.34^{b}	7.09^{b}
$T_{4\ ME}$	9.75^{a}	8.87^{a}	9.59^{a}	7.81^{a}	9.47^{a}	8.73^{a}
LSD	2.8953	1.3127	0.6726	0.6941	0.6419	0.5756
F-value	15.53*	71.45*	117.15*	235.78*	225.87*	119.35*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Table 19. *Allelopathic effect of L. camara leaf powder on germination percentage of test species*

Treatments		Test species					
Media		***T. aestivum***	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
Filter paper	10 mg	91^{a}	34^{b}	37^{b}	39^{b}	43^{b}	80^{a}
	Control	90^{a}	80^{a}	89^{a}	85^{a}	91^{a}	83^{a}
Soil	50 mg	90^{a}	29^{b}	35^{b}	31^{b}	32^{b}	81^{a}
	Control	91^{a}	81^{a}	90^{a}	86^{a}	92^{a}	84^{a}
Agar	10 mg	93^{a}	36^{b}	40^{b}	36^{b}	38^{b}	83^{a}
	50 mg	91^{a}	33^{b}	37^{b}	33^{b}	34^{b}	81^{a}
	Control	95^{a}	82a	91^{a}	86^{a}	93^{a}	85^{a}
LSD		13.622	12.454	16.410	16.07	14.544	16.880
F-value		26.14*	15.63*	21.56*	37.71*	22.14*	54.38*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

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Radical length

The data revealed that *C. album, P. minor* and *A. fatua* showing 52%, 5% and 50% radical length inhibition respectively as compared to control in *L. camara* leaf powder on filter paper, whereas, no significant effect on radical length of *T. aestivum, R. dentatus* and *E. helioscopia* showing resistance to dry powder. It is also clear from the result that *C. album, P. minor* and *A. fatua* showed 55%, 53% and 52% radical length inhibition respectively as compared to control in powder applied into soil. The results also declared that maximum (98%) radical length was noted for *T. aestivum, R. dentatus* and *E. helioscopia* (*Table 20*). In the present study, it was demonstrated that minimum radical length was noted for *C. album* i.e. 48% and 45% on filter paper and soil, respectively. The results of the current study indicated on agar the highest radical length reduction was noted for *P. minor* (36%), followed by *A. fatua* (33%) and *C. album* (32%) at 10 mg conc. Similarly, the highest radical length reduction was noted for *C. album* (53%), followed by *P. minor* (51%) *A. fatua* (50%) at 50 mg conc. The statistical data concluded that minimum radical length was noted for *P. minor* (64%) and *C. album* (37%) at 10 mg and at 50 mg conc., respectively (*Fig. 4b*).

Table 20. *Allelopathic effect of L. camara leaf powder on radical length (cm) of test species*

Treatments		**Test species**					
Media		***T. aestivum***	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
Filter paper	10 mg	9.1[a]	4.58[b]	7.91[a]	4.01[b]	9.1[a]	4.41[b]
	Control	9.4[a]	9.11[a]	7.98[a]	8.19[a]	9.2[a]	9.21[a]
Soil	50 mg	9.3[a]	4.36[b]	7.94[a]	3.86[b]	9.3[a]	4.26[b]
	Control	9.6[a]	9.13[a]	8.00[a]	8.21[a]	9.4[a]	9.41[a]
Agar	10 mg	9.7[a]	6.12[b]	8.20[a]	5.25[b]	9.4[a]	6.57[b]
	50 mg	9.5[a]	4.61[c]	8.19[a]	4.07[c]	9.2[a]	4.51[c]
	Control	9.8[a]	9.15[a]	8.21[a]	8.23[a]	9.6[a]	9.62[a]
LSD		3.2779	0.8692	0.8236	2.5388	1.503	0.9823
F-value		23.22*	498.76*	266.70*	47.00*	57.71*	66.95*

Means followed by different letters within one column differ significantly at P < 5%
*Significant at P < 1%

Plumule length

The data revealed that *E. helioscopia, C. album, R. dentatus* and *A. fatua* showing 54%, 53%, 51% and 50% plumule length inhibition respectively as compared to control in *L. camara* leaf powder on filter paper, whereas, no significant effect on plumule length of *T. aestivum* and *P. minor* showing resistance to dry powder. It is also clear from the result that *E. helioscopia, C. album, A. fatua* and *R. dentatus* showed 64%, 61%, 59% and 56% plumule length inhibition respectively as compared to control in powder applied into soil. The results also declared that maximum (98%) plumule length was noted for *T. aestivum* and *P. minor*. In the present study, it was demonstrated that minimum plumule length was noted for *E. helioscopia* i.e. 49% and 36% on filter paper and soil, respectively (*Table 21*). The experimental results of the current study indicated on agar the highest plumule length reduction was noted for *R. dentatus* (43%), followed

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by *E. helioscopia* (42%), *C. album* (42%) and *A. fatua* (37%) at 10 mg conc. Similarly, the highest plumule length reduction was noted for *C. album* (59%), followed by *E. helioscopia* (57%), *A. fatua* (56%) and *R. dentatus* (55%) at 50 mg conc. The statistical data concluded that minimum plumule length was noted for *R. dentatus* (67%) and *C. album* (41%) at 10 mg and at 50 mg conc., respectively (*Fig. 4c*).

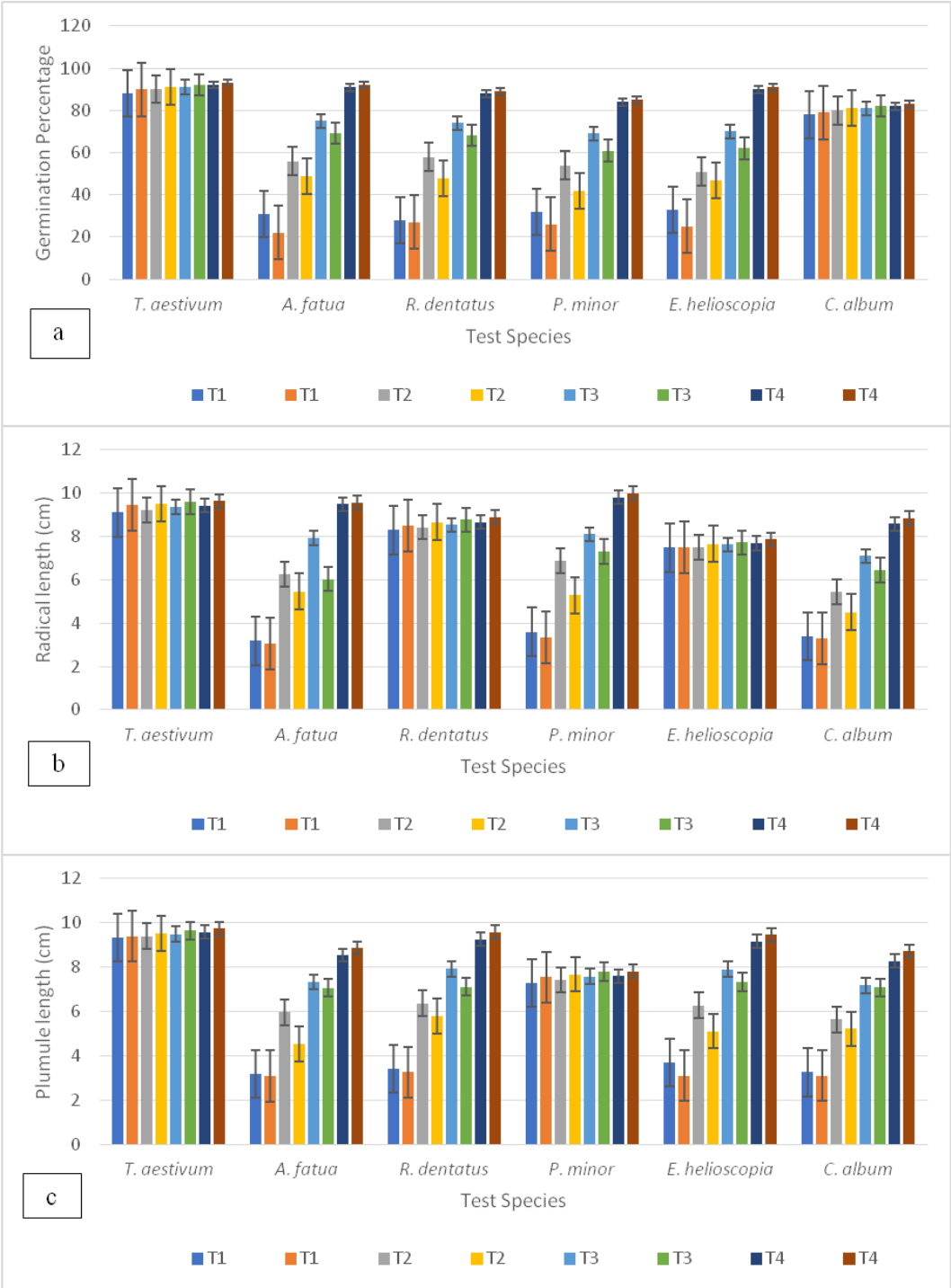

Figure 4. *Allelopathic potential of L. camara methanolic extract against test species on filter paper (FP) and soil (S) on: (a) germination percentage (b) ra*dical length (c) plumule length

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Table 21. *Allelopathic effect of L. camara leaf powder on plumule length (cm) of test species*

Treatments		Test species					
Media		***T. aestivum***	***A. fatua***	***R. dentatus***	***P. minor***	***E. helioscopia***	***C. album***
Filter paper	10 mg	9.1[a]	3.98[b]	4.61[b]	10.1[a]	3.29[b]	4.59[b]
	Control	9.4[a]	8.01[a]	9.48[a]	10.2[a]	7.09[a]	9.71[a]
Soil	50 mg	9.3[a]	3.26[b]	3.94[b]	10.3[a]	3.26[b]	3.86[b]
	Control	9.6[a]	8.03[a]	9.00[a]	10.4[a]	9.01[a]	10.01[a]
Agar	10 mg	9.7[a]	5.02[b]	5.20[b]	10.4[a]	4.15[b]	5.87[b]
	50 mg	9.5[a]	3.51[c]	4.19[c]	10.2[a]	3.06[c]	4.21[c]
	Control	9.8[a]	8.05[a]	9.21[a]	10.6[a]	7.13[a]	10.2[a]
LSD		3.4490	0.9763	1.9841	1.3929	0.9953	0.9834
F-value		21.59*	128.81*	33.17*	65.06*	51.17*	124.10*

Means followed by different letters within one column differ significantly at $P < 5\%$
*Significant at $P < 1\%$

Discussion

Natural herbicides obtained from allelopathic plants can help in reducing usage of synthetic herbicides for weed controlling. Resultantly these may environment friendly better agricultural products as well as alleviate human health concerns (Khan et al., 2014). *Lantana camara* is reported to possess phenolic, alkaloids and aromatic compounds which inhibit the growth and seed germination of adjacent plant by competing soil nutrients and fluctuating micro environment by producing dense thickets (Dobhal et al., 2010). Keeping this in view, the present study was performed for evaluating *L. camara* as allelopathic potential against some major weeds (*Phalaris minor, Avena fatua, Chenopodium album, Euphorbia helioscopia* and *Rumex dentatus*) of wheat crop.

The aqueous extract of *L. camara* significantly inhibited seed germination of *A. fatua* (42%) and *E. helioscopia* (36%) on filter paper and soil, respectively. Besides, there was lowest radical length (cm) in *A. fatua* being the most susceptible weed, while lowermost plumule length was noted in *E. helioscopia*. These results are in-line with past studies. The aqueous extract of *L. camara* significantly suppressed the growth and seed germination of different plant species including agricultural crops (Sharma et al., 2005; Ahmed et al., 2007). Our results were also in accordance with those of Hussain et al. (2011) who reported that leaf extract *L. camara* to be the most toxic for test species. Iramus et al. (2011) had observed that the retardation in root length of *Vigna radiata* was due to inhibitory effect of *L. camara* leaf extract and suppressive effect was concentration dependent. Jabeen and Ahmed (2009) stated that germination and subsequent growth of *Cucurbita pepo* was significantly reduced by leaf aqueous extract of *L. camara*. The germination inhibition was due to allelopathic action of some inhibitory chemical substances excreted by plants. Tadele (2014) described that the potential of leaf aqueous extract of *L. camara* on root and shoot elongation was species specific and concentration dependent. Enyew and Raja (2015) observed that *L. camara* leaf aqueous extract caused significant retardation in root elongation of *Zea mays* that may be attributed to the secondary metabolites produced by the extract. The germination and subsequent growth of *Eichhornia crassipes* was significantly checked

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by aqueous extracts from mature and young leaves of *L. camara*, caused tissues decay and damages in *E. crassipes* (Saxena, 2000).

The analysis of the data of hexane extract indicated that there was significant reduction in germination of *E. helioscopia* (35%), followed by *P. minor* (33%) and *A. fatua* (32%) on filter paper, while lowest radical length was observed in *A. fatua* and the lowermost plumule length in *R. dentatus*. Tadele (2014) stated that leaf hexane extract of *L. camara* significantly decreased germination of *Eragrostis teff*. Padhy et al. (2000) described that growth suppression in seed germination and vigor may be due to the presence secondary metabolites in *L. camara* extract. The allelopathic potential of leaf extracts of *L. camara* different concentrations were retarder to all growth parameters of *Vigna radiata* seeds. The growth of *Setaria italica*, *Lactuca sativa* and *Pennisetum americanum* was significantly checked by all parts of *L. camara* extracts (Hussain et al., 2011).

The methanolic extract of *L. camara* significantly inhibited seed germination of *R. dentatus* (68%), *A. fatua* (66%), *E. helioscopia* (63%) and *P. minor* (62%). Besides, the same extract significantly reduced radical length of *A. fatua* and plumule length of *R. dentatus* and *E. helioscopia*. Mishra (2015) presented the similar results and stated that *L. camara* has allelopathic effect on *Lepidium sativum* germination and growth. Ahmed et al. (2007) described the inhibitory potential of *L. camara* in different crops. Mishra (2012) stated that *L. camara* extract checked seed germination of *Parthenium hysterophorus* demonstrating the presence of inhibitory phytochemicals. Oudhia (2000) noticed significant reduction in seed germination of *Melilotus alba* by extract *L. camara*.

The results of sandwich method indicated significant reduction in germination percentage of *A. fatua* and *E. helioscopia* on filter paper and soil by applying *L. camara* leaf powder. There was no inhibitory effect on *T. aestivum*, *R. dentatus* and *E. helioscopia*. There was minimal radical length in *C. album* and plumule length in *E. helioscopia* that showed the most sensitive weeds against the *L. camara* leaf powder. Some of the studies reported inhibitory effect of *L. camara* on the germination and growth of various crops. The leaf powder of *L. camara* inhibited germination, radical and plumule length of radish and lettuce (Qiaoying et al., 2009), *P. hysterophorus* (Mishra and Singh, 2012), *Albizia procera*, *Acacia auriculiformis*, *Paraserianthes falcataria*, *Amaranthus tricolor*, *Abelmoschus esculentus*, *Vigna sinensis*, *Oryza sativa* and *Cucurbita pepo* (Mishra, 2012). Das et al. (2012) also noticed inhibition linked with the production of allelochemicals from the *L. camara* leaves that inhibit growth of adjacent plants by outcompeting for soil nutrients and altering micro environment by forming dense thickets.

Conclusion

This study was aimed at evaluating allelopathic potential of *L. camara* against some major weeds of wheat crop. The selected solvent extracts (i.e. aqueous, methanolic and ethanolic) and dried leaf materials significantly inhibited seed germination, radical and plumule length of the selected weeds without harming the wheat plants. Among all the tested extract, methanolic ones showed its supremacy in terms of growth and germination inhibition of the studied weeds. It can be concluded that *L. camara* methanolic extract can be explored in future studies in purifying and identifying herbicidal compounds to be used in future herbicidal products development.

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