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Allelopathic Potentiality of *Heliotropium curassavicum* L. and *H.bacciferum* Forssk.

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A POT EXPERIMENT was conducted under natural conditions in an open greenhouse to study the allelopathic potentiality of *Heliotropium curassavicum* and *H. bacciferum* on the growth parameters of *Calotropis procera* and *Faba sativa*. Ground shoot powder with three application rates of 2.5, 5 and 10 g per 8 kg soil for the two *Heliotropium* species treatment referred as T_1, T_2 and T_3; respectively, were evenly mulched on the soil surface of the test species. The present study showed that the inhibitory effect of *H.curassavicum* on the growth of the test species was generally more than that of *H. bacciferum*. Values of root-shoot (R:S) ratios for *C.procera* treated with either *H. curassavicum* or *H. bacciferum* mulches, were less than unity while the same measurements for *F.sativa* were more than unity. Less number of flowers per individual was recorded in the treated *F. sativa* in comparison to that of *C.procera*. Comparing dry matter allocation of *C. procera* plant organs in most growth stages and treatments demonstrated that, percent allocation of leaves > stem > root > flowers. Dry matter allocation to roots in the case of *F. sativa* plants treated with either *H.curassavicum* or *H. bacciferum*, gave maximum values as compared to other plant organs. Growth analysis of the two test species and the variation in growth criteria in response to the effect of mulching treatments included relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA) and specific leaf weight (SLW) were studied. The RGRs of the two test species generally decreased as the plant age proceeded. The present study recommends the use of the two *Heliotropium* species for the biocontrol of harmful shrubs such as *C. procera* and at the same time alerts of the inhibitory effect of these species on the growth of economic plants such as *F. sativa.*

Keywords: Allelopathic potentiality, *Heliotropium curassavicum*, *Heliotropium bacciferum*, Dry matter allocation, Growth parameters.

Allelopathy involves any direct or indirect harmful effect of one plant through release of chemical compounds on the other. These allelopathic chemicals inhibit seed germination or reduce growth of the other plant species. Moreover,

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allelochemicals affect cell division, production of plant hormones, membrane permeability, germination of pollen grains, mineral uptake, movement of stomata, pigment synthesis, photosynthesis, respiration, protein synthesis, nitrogen fixation, specific enzyme activities and development of conductive tissue (Rice, 1984; Djurdjević *et al*. 2012; Mansour, 2013). Allelochemicals include phenolic acids, coumarins, terpenoids and flavonoides. These compounds are released from the plants as vapour, as leachings from the foliage, as exudates from the roots, or in the course of breakdown or decomposition of dead plant residues. Allelopathy is existent in the natural and agricultural ecosystems. It is a mechanism by which weeds affect crop growth and yield. Allelopathy is possibly a significant factor in maintaining the present balance among the various plant species (Kim and Lee 2011). There is increasing evidence that many plant invaders interfere with native plants through allelopathy. This allelopathic interference may be a key mechanism of plant invasiveness (Inderjit *et al*., 2008). Several studies demonstrated the negative relationship between native and exotic species (Thorpe *et al*., 2009). There is much evidence that allelochemicals from weeds inhibit crop growth (Florentine *et al*. 2005). Farrag (2007) studied the allelopathic effects of three weeds; namely, *Heliotropium curassavicum, Bassia indica* and *Chenopodium ambrosioides* on the associated weeds and crops in the Nile Delta region, Egypt.

In Saudi Arabia, *Heliotropium curassavicum* L. and *Heliotropium bacciferum* (Boraginaceae) have become two of the most common polycarpic weeds infesting many Wadis and newly reclaimed fields at many areas of Taif regions (Farrag 2012). Because of their vigorous growth and natural ability to colonize the disturbed salt affected sand flats, the species spreads rapidly invading the newly reclaimed lands and the surrounding fields as a troublesome weed (Hegazy, 1994). The success of different *Heliotropium* species as weeds can be attributed to the production of adventitious root buds which allow for the plant's perennation and spread (Hegazy, 1994).

The aim of the current work is to compare the allelopathic potentiality of two invasive *Heliotropium* species (Boraginaceae); namely, *Heliotropium curassavicum* L. and *Heliotropium bacciferum* Forssk., on the growth of one important economic crop; *Faba sativa* (Fabaceae) and one common toxic shrub; *Calotropis procera* (Asclepiadaceae) in Taif.

Material and Methods

1. Materials

The seeds of the crop; *F.sativa* were obtained commercially from the store in Taif, while seeds of *C. procera* were collected from the plants of naturally growing populations at Wadi Al-Argy, Seesed, about 5 km east of Taif (21^0 $17^/$ N and 40^0 $29^/$ E and altitude of 1595m). Plastic pots (18 cm diameter and 25 cm depth) were used. The soil was obtained from the field study site. The soil samples were air-dried and passed through 2-mm sieve to separate litter and gravel. The air-dried sieved soil was filled into the experimental pots

(8 kg soil/pot). *H.curassavicum* and *H.bacciferum* plant materials for the purpose of mulching experiment were collected from naturally growing plants at Wadi Al-Argy, Seesed- Taif. The collected plant samples washed with distilled water then separated into shoots and roots air dried and finally grind the shoots to test the mulching purposes.

2. Experimental design

The experiment was conducted in an open greenhouse at Wadi Argy, under the external natural environmental conditions in Seesed area. The prevailing climatic conditions during the experimental period includes temperature which ranged between a minimum of 12.8ºC in November to a maximum value of 34.4ºC in July. Relative humidity ranged between minimum of 23% in June to a maximum value of 55% in November (Farrag, 2012). Ten seeds were sown in every pot at depth of 1cm. Ground shoot powder with three application rates of 2.5, 5 and 10 g per 8 kg soil for each *Heliotropium* species treatment referred as T_1, T_2 and T_3; respectively, were evenly mulched on the soil surface of the corresponding pot. In control treatment the seeds were sown in soils without mulching. Total of twelve pots were used for each treatment, three of which were harvested for each of the four growth stages; seedling, juvenile, mature and flowering. Seedling emergence was monitored daily. After the seedling emergence ceased, seedlings were thinned to the most similar healthy five individuals per pot. The pots were watered regularly and equally at the same time for all treatments when needed. The amount of water per pot was adjusted to avoid leaching of the soil water out of pots.

3. Harvest and measurements

Plant materials were harvested and data gathered at the four growth stages; seedling, juvenile, mature and flowering stages for all target plants. At each harvest stage, whole pot of each treatment was gently inverted and whole plants harvested individually by carefully clearing the soil with pressurized tap water. The growth criteria measurements included root depth, shoot height, leaf area, number of leaves and flowers. The whole plant then divided into separate organs; roots, stems, leaves, and reproductive organs (flowers), which then oven dried at 75ºC until constant weight. Dry phytomass was recorded for each plant organ. Five replicates were used for every measurement.

Root/shoot ratios, percent dry matter allocation and growth parameters including Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Leaf Area Ratio (LAR), Specific Leaf Area (SLA) and Specific Leaf Weight (SLW) were calculated according to Hunt (1978) by using the following equations: The RGR was calculated as gm $gm^{-1}day^{-1}$ over the time interval as: $RGR = (\ln W_2 - \ln W_1) / (t_2 - t_1)$ Where, W_1 and W_2 are weights at time t_1 and t_2, respectively. The NAR was calculated as gm mm^{-2} day^{-1} over the time interval as: $NAR = \{(\ln A_2 - \ln A_1) / (A_2 - A_1)\} X \{(W_2 - W_1) / (t_2 - t_1)\}$, and LAR calculated as mm^2 gm^{-1} as follow: $LAR= \{(\ln W_2 - \ln W_1) / (\ln A_2 - \ln A_1)\} X \{(A_2 - A_1)/ (W_2 - W_1)\}$ where, W_1, W_2 are weights and A_1, A_2 are leaf areas at time t_1 and t_2, respectively. The SLA was calculated as mm^2 gm^{-1} as: SLA = Leaf area / Leaf weight. The SLW was calculated as mg mm^{-2} as: SLW = Leaf weight / Leaf area

4. Statistical analysis

Data were analyzed by ANOVA test to determine the significance of differences among the mean values at P< 0.05 and P < 0.01 probability levels using a "general linear model" procedure of the Statistical Analysis System (SAS) program (SAS Institute, 1985). The correlation between RGR and other growth parameters was undertaken by using SPSS program version 10.

Results

1. Vegetative attributes

The effect of mulching using either *H. curassavicum* or *H. bacciferum* shoot powder on shoot height and root depth of *C. procera* and *F. sativa* demonstrated significant inhibitory effects on both shoot and root lengths in most growth stages (Fig. 1 , 2). The inhibitory effect of *H. curassavicum* was generally more than that of *H. bacciferum* as follows

The mean shoot and root lengths of *C. procera* treated with *H. curassavicum* powder showed significant (*p<0.01*) differences and varied as a function of mulch concentration and growth stages (Fig. 1). Average shoot lengths recorded 4.3, 3.9, 2.5 and 2 cm at the seedling growth stage for the treatments of control, T_1, T_2 and T_3; respectively, while these values greatly increased at the late growth stage (flowering) and recorded 84.7, 77.9, 72.4 and 62.4 cm for shoots of the same type of mulch and treatments. Root depths of *C. procera* followed the same inhibitory effect of mulch. For example, the measured root depths of *C.procera* were significantly (*p<0.05*) decreased from 36cm into 14.3cm for *C.procera* roots of control and T_3; respectively. Almost all *H. bacciferum* mulch concentrations showed the same inhibitory effect occurred in shoots and roots of *C. procera* but treated with *H. curassavicum* mulch (Fig. 1).

Considering the effect of *H.curassavicum* and *H.bacciferum* mulches on shoot and root lengths of *F.sativa*, the illustrated data in (Fig. 2) followed the same inhibitory effect of the mulch treatments on theses lengths through the different growth stages. Considering shoot heights of *F. sativa* treated with *H. curassavicum* at the flowering growth stage, the recorded means were 32.7, 25.7, 20.3 and 17.3cm for treatments control, T_1, T_2 and T_3; respectively, while the recorded values were 32.7, 29.3, 23.6 and 19cm for the same treatments and growth stage of *F. sativa* plants treated with *H. bacciferum* (Fig. 2). In addition, the recorded *F. sativa* average root depths and treated with *H. curassavicum*, were 47.3, 43, 22 and 14.6cm (*p*< 0.05) at the mature growth stage for the treatments of control, T_1, T_2 and T_3; respectively and in these values were relatively higher and recorded 29.6, 24.6, 19.7 and 17.3cm (p< 0.01) for roots of *F. sativa* plants treated with *H. bacciferum* at the same growth stage (Data not shown).

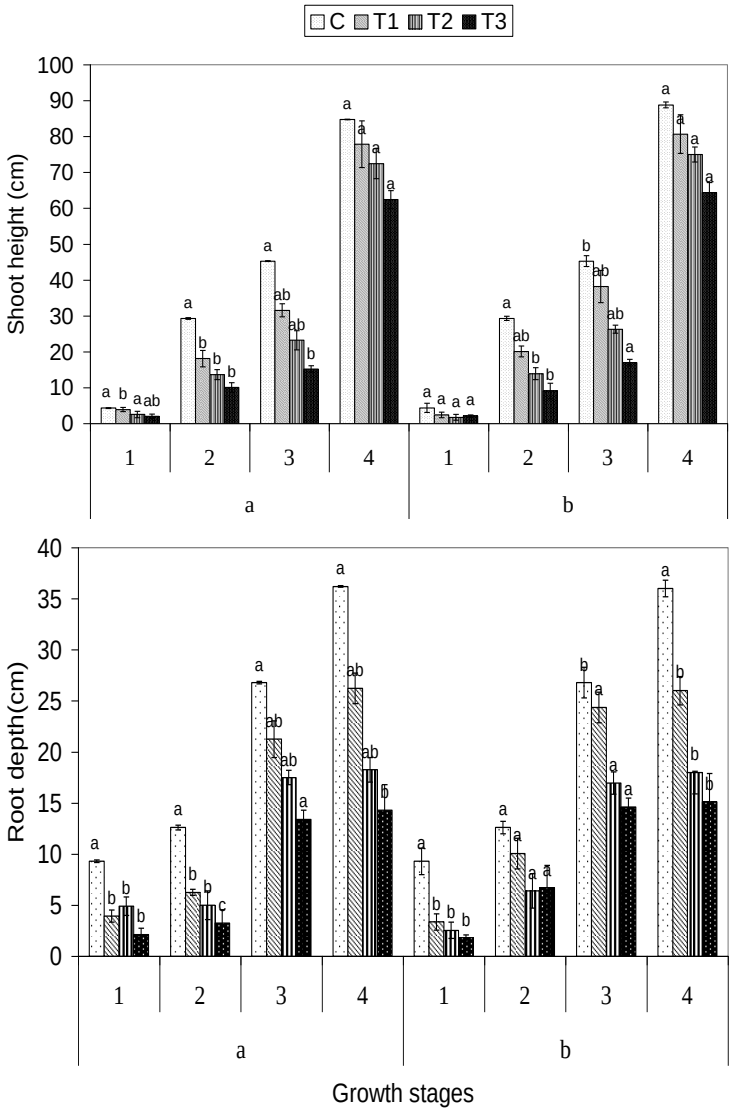


Fig.1. Mean and standard deviation of shoot height and root depth of *C. procera* growing under mulching treatment of *H. curassavicum* (a) and *H. bacciferum* (b) at different growth stages;1= Seedling, 2 = Juvenile, 3 = Mature and 4= Flowering. Vertical bar around the mean is the standard deviation. Values with the same letter were not significantly different according to the Dunnett test.

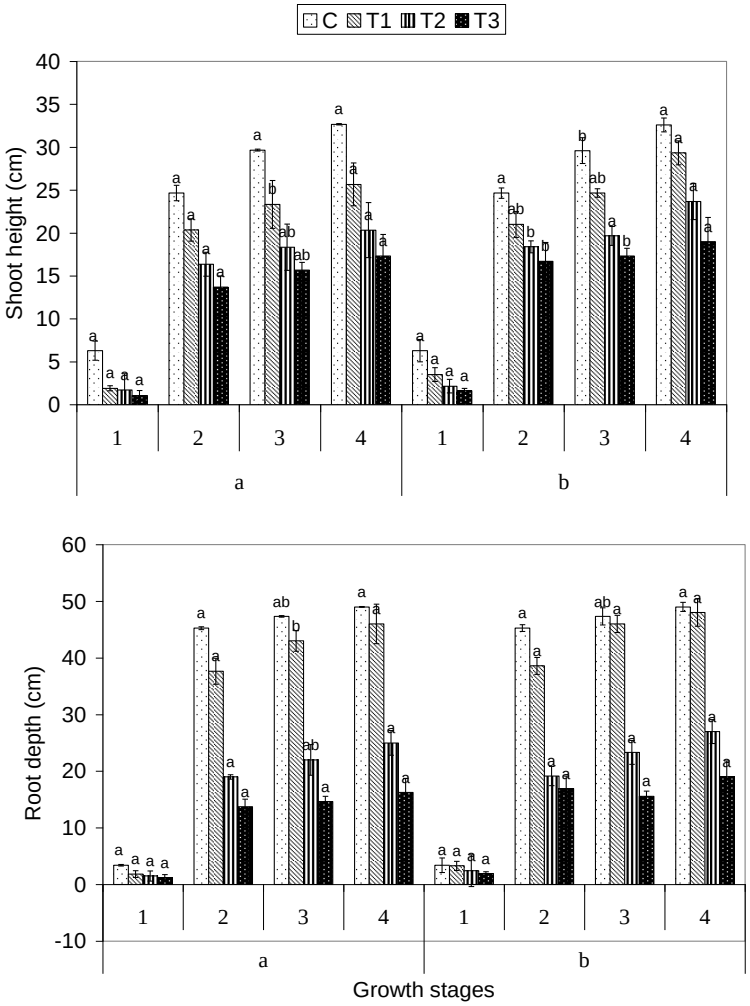
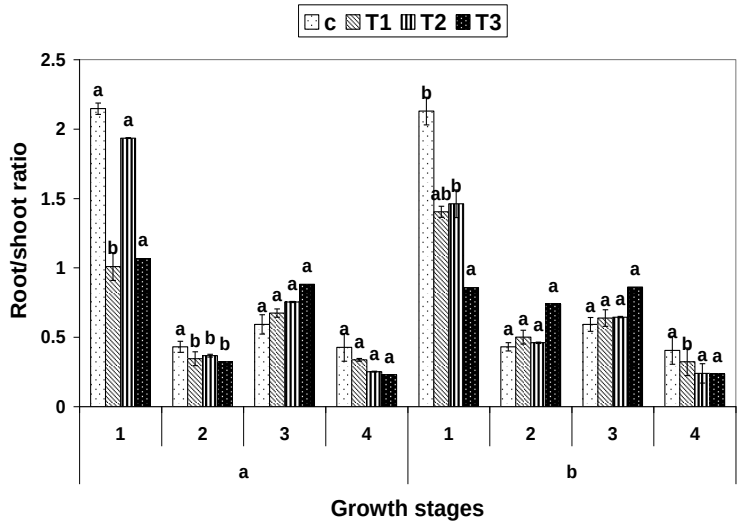


Fig. 2. Mean and standard deviation of shoot height and root depth of *F. sativa* growing under mulching treatment of *H. curassavicum* (a) and *H. bacciferum* (b) at different growth stages;1= seedling, 2 = juvenile, 3 = mature and 4= flowering. Vertical bar around the mean is the standard deviation.

The illustrated data in Fig. 3, showed that the values of root-shoot (R:S) ratios for *C. procera* treated with either *H. curassavicum* or *H. bacciferum* mulches, were (<1) except for the seedling growth stage, then those for *F. sativa* (>1). Considering (R:S) ratios that recorded by *C. procera* treated with *H.curassavicum* for instance, the values ranged between 0.32 and 0.43 in the juvenile growth stage using the different mulch concentrations, while the (R:S) ratios attained by *F. sativa* ranged between 1.01 and 1.83 for the same growth stage and treatments (Fig. 3).

C. procera



F. sativa

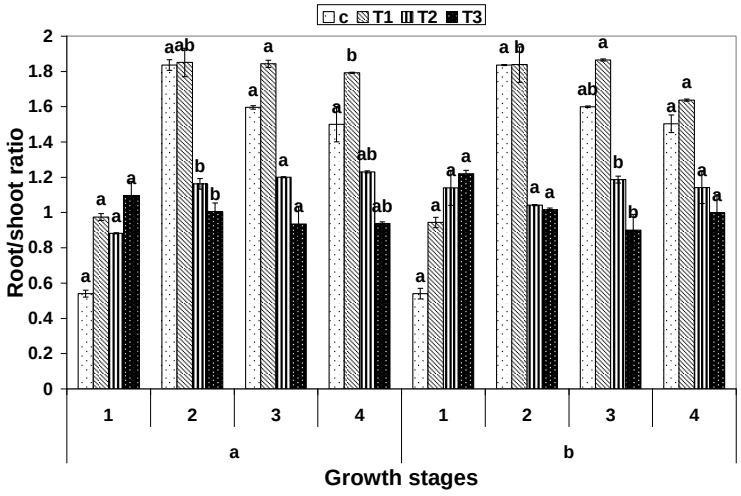


Fig. 3. Mean and standard deviation of root/shoot ratio of *C. procera* and *F. sativa*, growing under mulching treatment of *H. curassavicum* (a) and *H. bacciferum* (b) at different growth stages;1= seedling, 2 = juvenile, 3 = mature and 4=flowering. Vertical bar around the mean is the standard deviation.

2. Reproductive attributes

Less number of flowers per individual was recorded in *F.sativa* in comparison to that of *C. procera*. The average number of flowers were 10.33, 9.66, 9.33 and 8.33 for *C.procera* plants mulched by *H. curassavicum*, while the recorded ones were significantly ($p<0.05$) reduced to 6.66, 2.33, 1.66 and 1 in the case of *F. sativa* plants. In addition, the inhibitory effect of *H. curassavicum* on the number of flowers of the two studied test species was more than that of *H.bacciferum*. The average number of flowers per *F. sativa* individual treated by *H. bacciferum* were 3.54, 2.56 and 1.33 and these values relatively decreased into 2.33, 1.66 and 1 for the same test species but treated with *H. curassavicum* (Table 1).

TABLE 1. Number of flowers of *C. procera* and *F. sativa* subjected to the mulching treatment of (a) = *H. curassavicum* and (b) = *H. bacciferum* in the flowering stage. Mean values are given and values between bracts are the standard deviations. *P<0.05, **P<0.01, n.s. = non significant.

Treatment	*C.procera*		*F.sativa*	
	(a)	**(b)**	**(a)**	**(b)**
Control	10.33 ± 1.88^{a}	11.66 ± 1.24^{a}	6.66 ± 1.69^{a}	7.66 ± 0.59^{a}
T_1	9.66 ± 0.94^{a}	10.33 ± 0.48^{ab}	2.33 ± 0.47^{b}	3.54 ± 0.12^{ab}
T_2	9.33 ± 0.47^{a}	9.66 ± 0.48^{ab}	1.66 ± 0.47^{b}	2.56 ± 0.08^{a}
T_3	8.33 ± 0.47^{a} n.s.	8.66 ± 0.45^{b} *	1.00 ± 0.01^{b} *	1.33 ± 0.01^{b} **

3. Dry matter allocation

The allocation of dry matter to leaves of *C. procera* plants mulch by *H.curassavicum* was higher than the other plant organs in almost all growth stages except the juvenile stage (Fig. 4, a). The percent of dry matter allocated to leaves reached 49.02 % in *C. procera* treated plants (T_1) by *H. curassavicum* during the flowering growth stage, while the recorded dry matter allocations for stem, root and flowers were 34.04, 16.71 and 0.28%; respectively. Maximum allocation to *C. procera* leaves (71.89%) was recorded in the seedling stage for control plants, while minimum allocation to the same organ (9.95%) was recorded in the *C. procera* plants treated by T_2 rate of *H. bacciferum* mulch (Fig. 4,b). In general, comparing dry matter allocation of the different *C. procera* plant organs in most growth stages and treatments demonstrated that, percent allocation of leaves > stem > root > flowers.

In contrast to the above mentioned results, dry matter allocation to roots in the case of *F. sativa* plants treated with either *H. curassavicum* or *H. bacciferum*, gave maximum values as compared to other plant organs. The recorded dry matter allocation for *F. sativa* plants treated by *H. bacciferum* (T_2) were 46.39, 38.14 and 15.46% in root, leaves and stem; respectively (Fig. 5, a). Moreover,

maximum allocation which occurred in *F. sativa* root (49.57%), was recorded in plants subjected to T_2 *H. bacciferum* mulch (Fig. 5,b). Generally, the illustrated data revealed that, the allocation of *F. sativa* dry matter was in the order towards root> leaves> stem > flowers, which did not follow the same pattern mentioned above in the case of *C. procera*.

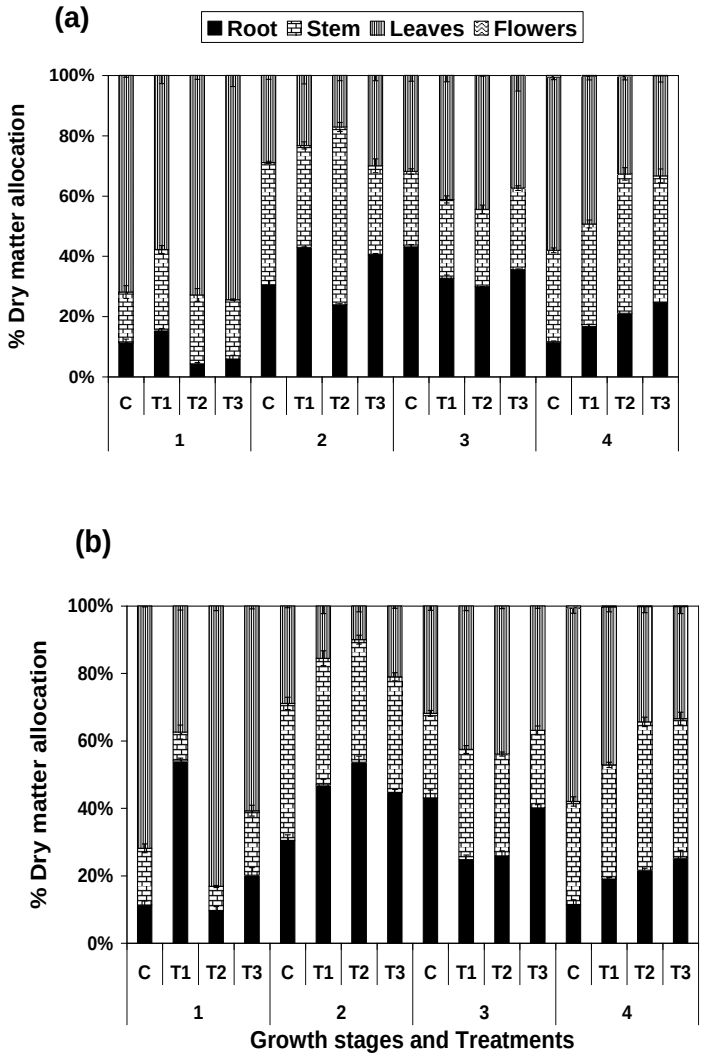


Fig. 4. Dry matter allocation of *C. procera* subjected to the mulching treatment of *H. curassavicum* (a) and *H. bacciferum* (b) at different growth intervals;1=seedling-juvenile, 2=juvenile-mature and 3= mature-flowering. Vertical bar around the mean is the standard deviation.

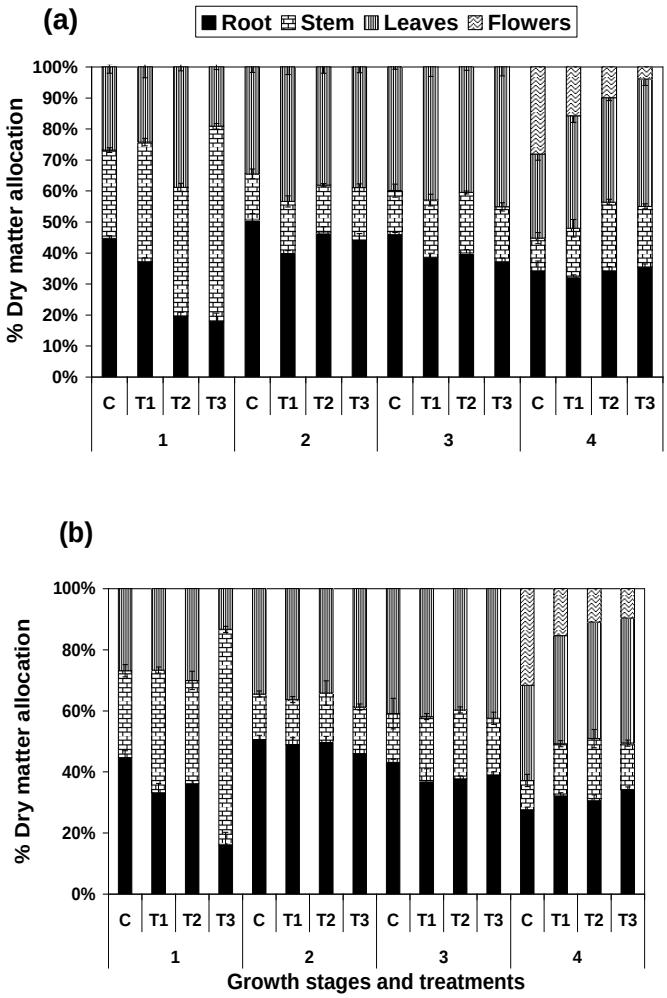


Fig. 5. Dry matter allocation of *F. sativa* subjected to the mulching treatment of *H.curassavicum* (a) and *H. bacciferum* (b) at different growth intervals; 1=seedling-juvenile, 2=juvenile-mature and 3= mature-flowering. Vertical bar around the mean is the standard deviation.

4. Growth analysis

Growth analysis of the two test species and the variation in growth parameters in response to the effect of mulching treatments included relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA) and specific leaf weight (SLW) were illustrated in Fig. (6-9). The correlation between RGR and other growth parameters is shown in Table 2.

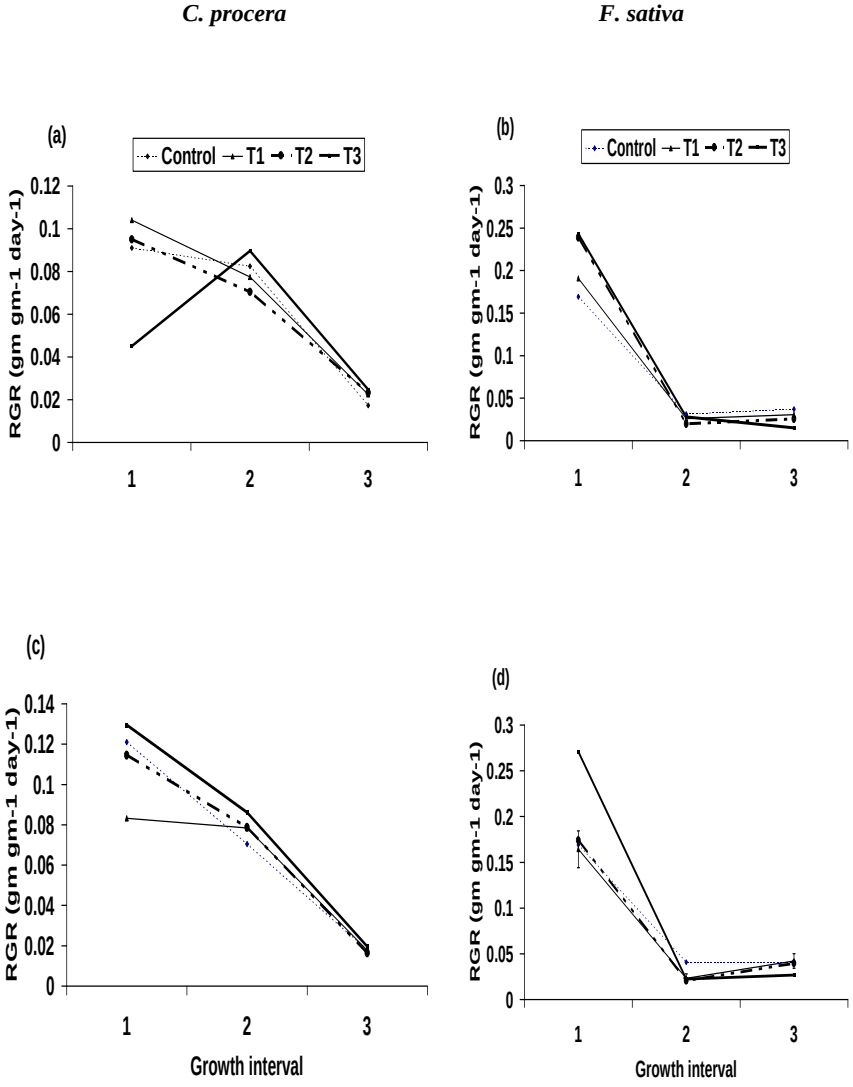


Fig. 6. Relative growth rate (RGR) of *C. procera* (a,c) and *F. sativa* (b,d) subjected to the mulching treatment of *H. curassavicum* (a,b) and *H.bacciferum* (c,d) at different growth intervals;1=seedling-juvenile, 2= juvenile-mature and 3= mature-flowering. Vertical bar around the mean is the standard deviation.

C. procera ***F. sativa***

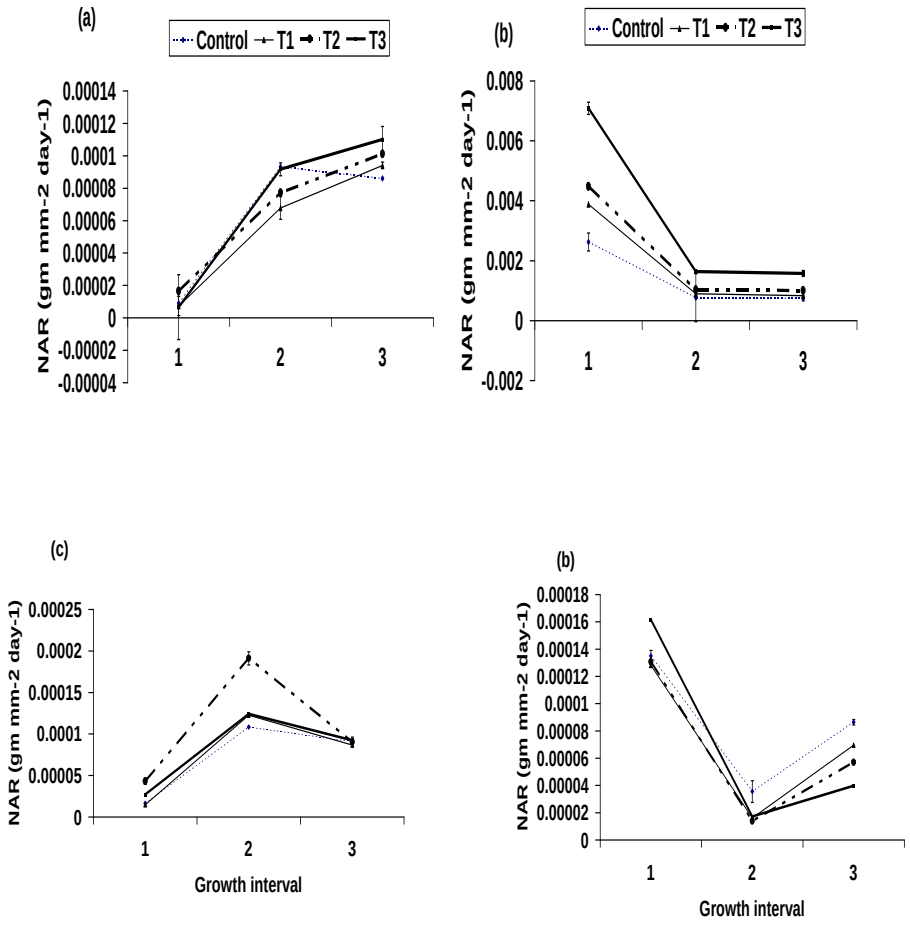


Fig. 7. Net assimilation rate (NAR) of *C.procera* (a,c) and *F. sativa* (b,d) subjected to the mulching treatment of *H. curassavicum* (a,b) and *H. bacciferum* (c,d) at different growth intervals;1= seedling-juvenile, 2=juvenile-mature and 3= mature-flowering. Vertical bar around the mean is the standard deviation .

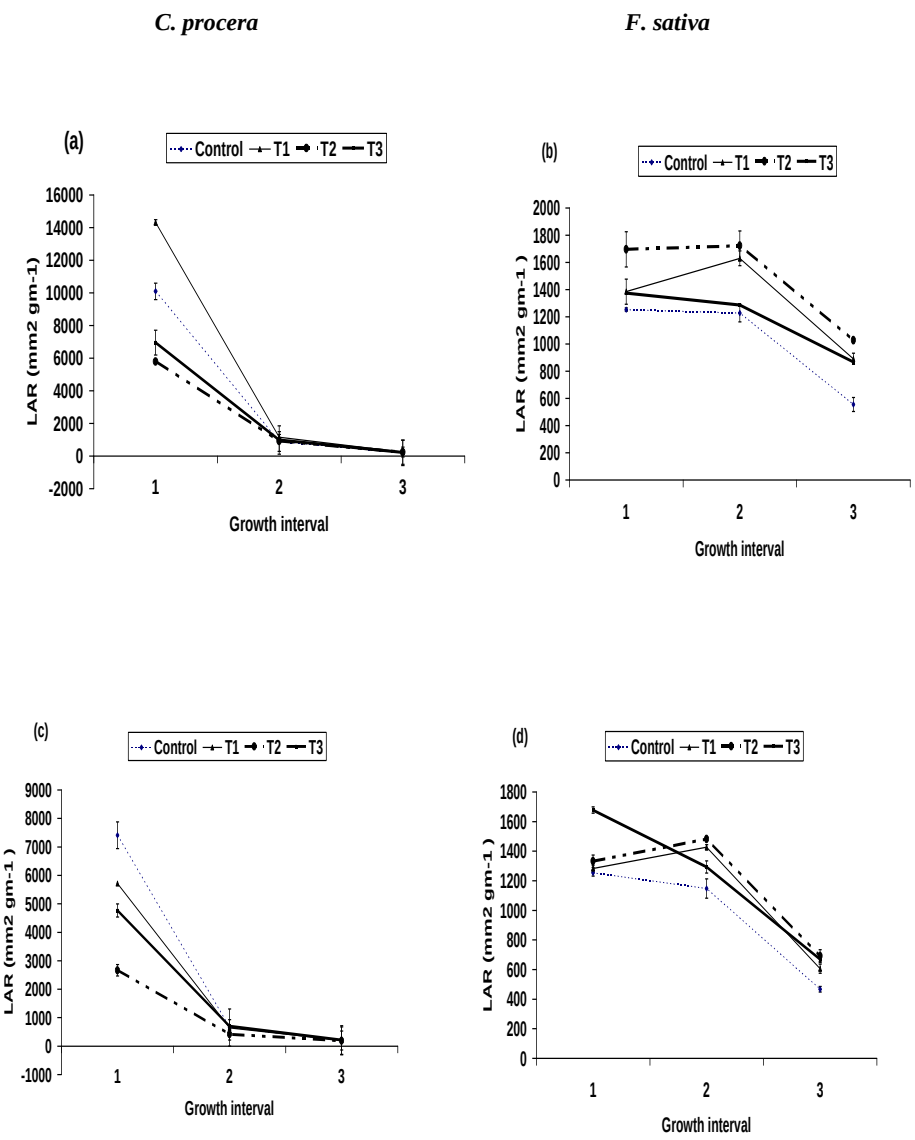


Fig. 8. Leaf area ratio (LAR) of *C. procera* (a,c) and *F. sativa* (b,d) subjected to the mulching treatment of *H. curassavicum* (a,b) and *H. bacciferum* (c,d) at different growth intervals;1=seedling-juvenile,2=juvenile-mature and 3=mature-flowering. Vertical bar around the mean is the standard deviation.

C. procera ***F. sativa***

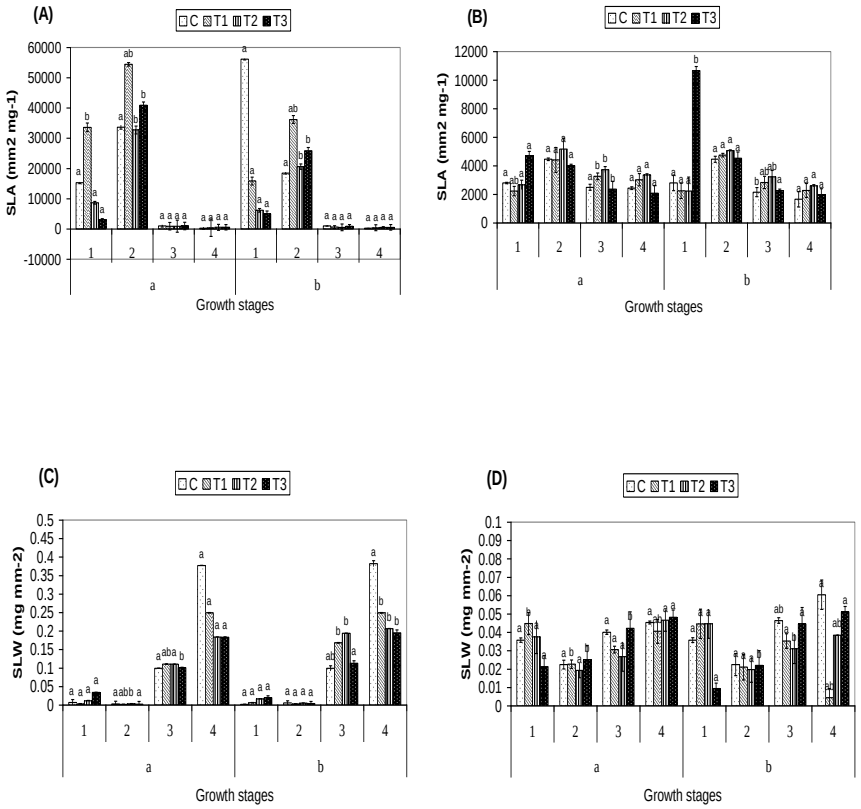


Fig. 9. Specific leaf area (SLA) and specific leaf weight (SLW) of *C. procera* (A,C) and *F. sativa* (B,D) subjected to the mulching treatment of *H. curassavicum*(a) and *H. bacciferum* (b) at different growth stages; 1= seedling, 2= juvenile, 3= mature and 4-flowering. Vertical bar around the mean is the standard deviation.

TABLE 2. Correlations between the relative growth rate (RGR) and other growth parameters; net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA) and specific leaf weight (SLW) of the test species as affected by mulching treatment of (a) = *H. curassavicum* and (b) = *H. bacciferum*, using Pearson correlation coefficient (Two-tailed test). *P<0.05, **P<0.01. r = correlation coefficient.

Test species	NAR				LAR			
	(a)		(b)		(a)		(b)	
	r	P	r	P	r	P	r	P
C. procera								
Control	**0.993****	0.006	**0.350**	0.560	**0.775**	0.235	**0.975***	0.018
T_1	**0.896**	0.144	**0.448**	0.632	**0.546**	0.264	**0.981***	0.019
T_2	**0.457**	0.674	**0.349**	0.563	**0.864**	0.279	**0.866**	0.146
T_3	**0.465**	0.451	**0.279**	0.731	**0.893**	0.220	**0.909**	0.091
F. sativa								
Control	**-0.993**	0.077	**-0.549**	0.825	**0.836**	0.370	**0.917**	0.347
T_1	**-0.870**	0.253	**-0.275**	0.975	**1.000****	0.008	**0.961***	0.078
T_2	**-0.786**	0.335	**0.517**	0.654	**1.000****	0.006	**0.994**	0.070
T_3	**-0.151**	0.860	**0.531**	0.643	**0.798**	0.412	**.953***	0.050

	SLA				SLW			
C. procera								
Control	**0.639**	0.361	**0.993****	0.007	**-0.929**	0.071	**-0.914**	0.086
T_1	**0.607**	0.393	**0.858**	0.142	**-0.809**	0.191	**-0.915**	0.085
T_2	**0.998***	0.062	**0.636**	0.364	**-0.718**	0.282	**-0.837**	0.163
T_3	**0.738**	0.282	**0.851**	0.149	**-0.452**	0.548	**-0.961***	0.039
F. sativa								
Control	**0.985***	0.018	**0.972**	0.082	**-0.982**	0.082	**-0.947**	0.209
T_1	**0.954**	0.194	**0.982**	0.079	**-0.956**	0.187	**-0.974**	0.134
T_2	**0.971**	0.155	**0.987**	0.103	**-0.959**	0.183	**-0.987**	0.105
T_3	**1.000****	0.006	**0.997***	0.046	**-0.853**	0.051	**-0.994**	0.069

4.1. Relative growth rate

The RGRs of the two test species generally decreased as the plant age proceeded. Considering *C. procera* treated with *H. curassavicum*, the recorded RGRs for control, T_1, T_2 and T_3 plants were 0.09, 0.1, 0.09 and 0.04 (gm gm^{-1} day^{-1}) during the seedling growth stage, while these values greatly reduced into 0.017, 0.022, 0.023 and 0.025 (gm gm^{-1} day^{-1}) at the flowering growth stage (Fig. 6,a). The same trend followed on treatment of *C. procera* by *H. bacciferum* (Fig. 6,c).

The RGRs for *F. sativa* plants treated by either *H. curassavicum* (Fig. 6,b) or *H. bacciferum* (Fig. 6,d) mulches showed similar trend *C. procera* but with one exception that the last two growth stages gave nearly equal values. In other words, RGRs in the early growth stage (seedling-juvenile) of *F. sativa* was affected by mulches than the late growth stages.

*4.2. Net assimilation rat*e

The effects of *H. curassavicum* and *H. bacciferum* on the NARs of *C. procera* and *F. sativa* was illustrated in Fig. 7.

The illustrated data revealed that the variations of NARs among the two test species were dependent on the test species and the growth stage. NAR of *C. procera* plants treated with *H. curassavicum* gave the lowest values at the seedling-juvenile growth interval for control and of the mulching treatments. The highest NAR values were recorded for the same treatments but at the mature-flowering growth interval (Fig. 7,a). Similarly, the effect of *H. bacciferum* mulch on the NAR of *C. procera* showed the same trend with the exception of the second growth interval, which showed the highest value (Fig. 7,c).

Unlike to the obtained NAR results for *C. procera*, the recorded NAR values for *F. sativa* decreased as the plant ages. Maximum NAR values were recorded in the first growth interval (seedling-juvenile) then decreased at the following growth intervals (Fig. 7, b and d).

4.3. Leaf area ratio

The effect of *H. curassavicum* and *H. bacciferum* mulches on the LARs of the two test species was illustrated in Fig. 8. Both *C. procera* and *F. sativa*, attained the highest LAR values in the first growth interval (seedling-juvenile) and then these values decreased in the subsequent growth intervals recording the minimum values in the late growth interval (mature-flowering). *C. procera* plants treated with *H. curassavicum* recorded the maximum LAR values among the different test species as it recorded 10086.75, 14303.54, 5790.18 and 6943.79 (mm^2 gm^{-1}) in control, T_1, T_2 and T_3 treated plants; respectively, during the seedling- juvenile growth (Fig. 8, a). Similar trend followed by *C. procera* treated with *H. bacciferum* and illustrated in Figure 8,c. LAR for *F.sativa* plants showed relatively smaller values in comparison to that of *C. procera*. Minimum LAR values were recorded for *F. sativa* plants treated by *H. bacciferum* in the third growth interval (mature-flowering) recording 554.2, 604.6, 690.5 and 669.2 (mm^2 gm^{-1}) in control, T_1, T_2 and T_3 treated plants; respectively (Fig. 8,d).

4.4. Specific leaf area

There was general trend of decrease of the SLA values as the plant mulch treatment increase and as plants age (Fig.7). Plants of *C. procera* treated with *H. curassavicum* recorded SLA values amounted to 55287.95, 33589.76, 8644.06 and 2960.21 mm^2 mg^{-1} in control, T_1, T_2 and T_3 plants, respectively in the seedling growth stage. These values are reduced gradually in the subsequent growth stages recording minimum values amounted to 265.23, 401.04, 544.81 and 545.29 mm^2 mg^{-1}, respectively, for the same treatments during the flowering growth stage of the same plant. In addition, the SLA values of control plants were relatively higher than that of treated plants using either one of the two mulch powders. For example, SLA in the mature growth stage of *C. procera* treated by *H. bacciferum* was 1010.52 mm^2 mg^{-1} and this value greatly reduced

to about its half (594.67 mm^2 mg^{-1}) using the first mulch treatment (T_1). The data revealed greater SLA values using either *C. procera* or *F. sativa* plants treated with *H. bacciferum*, than the test plant treatments by *H. bacciferum*. The recorded SLA values were 906.72 and 3731.01 mm^2 mg^{-1} for *C. procera* and *F. sativa* plants; respectively, and treated by (T_2) *H. curassavicum* during the mature growth interval. These values were greatly reduced into 515.71 and 3218.42 mm^2 mg^{-1} for the same plants and treatment but using *H. bacciferum*.

4.5. Specific leaf weight

Values of SLA and SLW for the two test species under the allelopathic potential of *H. curassavicum* and *H. bacciferum* was illustrated in Fig. 9. There was a reduction in SLA as the amount of mulch increased and as the test plants aged (Fig. 9, A and B). *C. procera* treated with *H. curassavicum* mulch showed the highest SLA values during the juvenile growth stage (Fig. 9, A). These values decreased gradually in the subsequent growth stages recording minimum values of 265, 401, 484 and 512 (mm^2 mg^{-1}) for the same plant and treated with *H. bacciferum* during the flowering growth stage (Fig. 9, A). *F. sativa* showed smaller SLA values (Fig. 9, B) in comparison to those of *C. procera*. In addition, there was no clear trend on comparing the SLW values of control and treated plants using different mulch treatment among the different test species (Fig. 9, C and D).

Correlation between RGR and other growth variables was given in Table 2. The data demonstrated that RGR was positively correlated with NAR, LAR and SLA, and was negatively correlated with SLW for all treatments of *C. procera*. *F. sativa*, showed negative correlation between RGR and NAR, SLW values and positive correlation with LAR and SLA. Considering *C. procera* treated with *H. curassavicum*, RGR values are highly and positively correlated with NAR values (r=0.993, P<0.01) in control plants, compared to relatively weaker but positive correlations in the treated plants by *H. bacciferum* (Table 2). The RGR values were positively and strongly correlated with NAR in both test plants using the mulches of the two *Heliotropium* species. Moreover, mulch treatments resulted in the high values of the correlation between RGR and SLA in the case of *F. sativa* and low correlations in *C. procera*.

Discussion

1. Vegetative attributes

Allellochemicals of *H. curassavicum* were identified as esters of the nonhepatotoxic saturated necine, trachelanthamidine (Subramaniam *et al.*, 1980). In addition, allelochemicals of *H. bacciferum* were reported and isolated as an alkaloid related to acetyl indicine (Farrag *et al.*, 2013).

Root length is found to be statistically more accurate than seed germination in assessing the response of test plants to allelochemicals (Cope, 1982). In accordance with inhibitory effects of the two *Heliotropium* mulches on the shoot height and root depth of the two test species of the present study, a reduction of

plant growth as influenced by allelochemicals was reported by several investigators (Jabeen *et al.,* 2011).

The current results which showed much inhibitory effects of the two *Heliotropium* species on both test species; *C. procera* and *F. sativa*, in the late growth stages, was explained by Farrag (2007). He reported that, the inhibitory effect of allelochemicals released by the plant mulch on shoot height and root depth of the other test species was observed in the late growth stages. Moreover, the accumulation of allelochemicals in the body of the test species may explain this behavior. In addition, soil microbes play an important role in the qualitative and quantitative availability of allelochemicals (Raoof and Siddiqui 2012). DeFrank and Putnam (1985) reported that soil-borne actinomycetes could enhance allelopathic effects. This may explain that the root depth of the test species of the present study was more affected by the inhibitory effect of allellochemicals than that of shoot length.

The values of root-shoot (R:S) ratios for *C.procera* and *F.sativa* treated plants with either *H.curassavicum* or *H.bacciferum* mulches, were less than those of untreated plants (controls), this was explained by Nilsson (1994) who suggested that the decrease in root/shoot ratio as a response to nutrient deficiency appears to be applied for plants subjected to allelopathic interactions.

2. Reproductive attributes and dry matter allocation

Less number of flowers per individual was recorded in the treated plants as compared with control plants of the present study. In this regard, many authors (Bich and Noguchi 2012) have reported the inhibitory effects of allelochemicals on the chlorophyll content and net photosynthetic rate of their test species which intern affect the reproductive opportunity of the test species. This feature is considered as a plastic response of the allelopathically stressed plants which enables them to live but with a diminished reproductive growth (Raynal and Bazzaz 1975).

3. Growth analysis

The relative growth rate of plants is determined by their genetic background and by environmental conditions (Rafael *et al.* 2005). The RGRs of most test species of the present work generally decreased with plant's age. This is in agreement with slow RGR that was observed by Hegazy and Ismail (1992) as a result of decreased age-specific LAR and slow NAR that reflect the decreased amount of leaf production with age resulting in slower growth. On the other hand, RGRs of controls of the present work are generally higher than that of treated plants especially in the case of *C. procera*. The slow RGR of treated plants may be implied by the toxic allelochemicals released from the mulch of the two *Heliotropium* species. In addition, the higher RGR of controls as compared to treated plants may be explained by the increment of dry matter allocated to the leaves. This means that better RGR in controls and mild treated plants (T_2) as compared to high mulch treated plants (T_3). Similarly, Sayed and Hegazy (1994), found that the pattern of RGR increment followed that of dry matter allocated into vegetative parts (stem and leaves) and a decrease in RGR

resulted from an increased dry matter allocated to sexual structures (flowers and fruits) at the expense of vegetative parts. In addition, the reduced dry mass and RGR of rice with increased density of lotus rhizomes indicates a possible response to allelopathic interference (Hegazy *et al.,* 2001). The observed increase in RGR during the seedling-juvenile growth interval which was followed by a decrease in the later growth intervals was observed in *F. sativa*. This may be explained by the fact that the growth rate in the seedling- juvenile growth interval is normally the most rapid in the life of desert plants in comparison to the subsequent growth intervals (Burdon and Harper 1980).

The wide variation in RGR among species was explained mainly by the variation in the plant morphological variables, such as LAR and in particular the SLA. This finding is in agreement with many other studies supporting SLA as a major factor associated with variation in the RGR (Chengxu *et al.,* 2011).

In accordance with findings of Farrag (2007), the variation of NAR between the two test species and among the control and treated plants of the same test species was very dynamic with age. Variability of NAR values among different species was parallel to the fluctuations in the RGR values. The test species attained the highest LAR values in the first growth interval, emergence-seedling, and then the values decreased in the subsequent growth intervals. This trend could be attributed to the decrease of the SLA values as the plants age. The positive correlation between RGR and other growth variables is in agreement with findings of many authors (Rafael *et al*., 2005). In addition, environmental conditions determine both the realized RGR and the relative importance of the other growth components. Studies have challenged the general view of SLA as a major determinant of RGR. Shipley (2002) argued that the commonly reported result that "the interspecific variation in RGR is determined primarily by SLA", is partly due to low irradiance used in most experiments. Therefore, the relative importance of SLA and NAR would change depending on the irradiance perceived by plant. In another study, Loveys *et al.,* (2002) found that RGR was significantly and positively correlated with NAR, when plants were cultivated at 18 ^{o}C. However, when growth temperature increased to 23 or 28 ^{o}C the RGR pattern switched, and correlated positively with SLA, which is in agreement of results of the present work.

Conclusion

In conclusion, the present study revealed that mulch treatments with the invasive plants *H. curassavicum* and/or *H. bacciferum* greatly suppressed the vegetative growth and dry matter allocation of the two test species. Moreover, the allelopathic effect of both *H. curassavicum* and *H. bacciferum* concerning number of flowers showed more inhibitory effect towards *F. sativa* than *C. procera*. Root/shoot ratio of control plants were generally reduced under the mulch effect and this reduction reaches its maximum in the late growth stages. The RGRs of most test species generally decreased with age as a result of decreased age-specific LAR and slow NAR. Variability of NAR values among different species may be explained by the fluctuations in the RGR values of this

species. Correlation between RGR and other growth variables demonstrated that RGR positively correlated with NAR, LAR and SLA for all treatments of *C. procera*, while the test species *F. sativa*, showed negative correlation between RGR and NAR values and positive correlation with LAR and SLA. The present study recommend the use of the two *Heliotropium* species for the biocontrol of harmful shrubs like *C. procera* and at the same time alert for the inhibitory effect of these species on the growth of economic plants like *F. sativa*.

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التضاد الكيميائي لنباتي الرحب و الحباليا

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تم إجراء التجربة الحالية فى صوبة مفتوحة تحت الظروف الطبيعية بهدف دراسة قدرة التضاد الكيميائي لنوعين من الهليوتروبيوم وهما نباتي الرحب و الحباليا وتأثيرهما على مقاييس النمو المختلفة لنباتي العشار و الفول. أستخدمت ثلاث تركيزات من مطحون الجزء الخضري لنباتي الرحب و الحباليا كل على حده و بالمعدلات التالية: 2.5، 5 و 10 جم مطحون بالإضافة إلي المعاملة الضابط و التي لم يضف اليه اى مطحون وتخلط على سطح التربة في أصيص بكل منها 8كجم من التربة. أوضحت الدراسة الحالية أن التأثير المثبط للمعالجة بمطحون الرحب على نمو النباتين المستهدفين (العشار و الفول) كان أكثر وضوحا من مثيله في حالة استخدام مطحون الحباليا. سجلت النسب بين الجذر و الساق لنبات العشار و المعالج بكل من مطحوني الرحب أو الحباليا، قيما أقل من الواحد الصحيح في معظم مراحل النمو بينما زادت نفس النسب عن الواحد الصحيح في حال التأثير بالمطحونين على نبات الفول. أوضحت الدراسة إنخفاضا واضحا لعدد الأزهار لكلا النباتين المستهدفين عند التأثير بأيا من المطحونين مقارنة بالنباتات غير المعالجة وبخاصة في حالة نبات الفول. سجل توزيع المادة الجافة لنبات العشار و المعالج بالمطحونين تحيزا واضحا للأوراق ويليه السيقان ثم الجذور و في الأخير تأتي الأزهار. أوضحت الدراسة أن توزيع المادة الجافة في حالة نبات الفول ينحاز للجذور مقارنة بالأعضاء النباتية الأخرى. أشتملت دراسة تحليل النمو للنباتين المستهدفين تحت تأثير مطحوني الرحب أو الحباليا على معدل النمو النوعي، معدل التمثيل الصافي، نسبة مساحة الورق، مساحة الورقة النوعي ووزن الورقة النوعي. بينت الدراسة إنخفاضا عاما لمعدلات النمو النسبية لنباتي الدراسة عند تقدمهما في العمر. أوصت الدراسة الحالية بإستخدام نوعي الهليوتروبيام في المكافحة الحيوية للنباتات الضارة كنبات العشار,حذرت الدراسة في الوقت نفسه من خطورة هذين النوعين على المحاصيل الإقتصادية الهامة كالفول.

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