International Journal of Plant & Soil Science

31(1): 1-10, 2019; Article no.IJPSS.52891
ISSN: 2320-7035

Physiological Response of *Capsicum annuum* L. to Aqueous Extracts of Allelopathic Plants: A Case of *Tithonia rotundifolia* and *Murraya koenigii*

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Authors' contributions

This work was carried out in collaboration among all the authors. Authors OOO, MOT and AAO conceived the study and participated in its design and coordination and helped to draft the manuscript. Authors MOT and AAO carried out laboratory study, plant measurements and statistical analysis. Author AAO participated in the design of the study, helped to draft the manuscript and performed the statistical analysis. All the authors managed the literature search and writing of the final manuscript. All the authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2019/v31i130199
Editor(s):
(1) Dr. Yong In Kuk, Department of Development in Oriental Medicine Resources, Sunchon National University, South Korea.
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Reviewers:
(1) Justina Nwandimma Nwangwa, University of Calabar, Nigeria.
(2) Nguyen Thi Hieu Trang, Research and Development Center for High Technology Agriculture, Vietnam.
Complete Peer review History: http://www.sdiarticle4.com/review-history/52891

Original Research Article

Received 25 September 2019
Accepted 29 November 2019
Published 12 December 2019

ABSTRACT

The present study evaluated the allelopathic potential of fresh shoot aqueous extracts of *Tithonia rotundifolia* (FSET) and *Murraya koenigii* (FSEM) on the germination of seeds, growth, chlorophyll, ascorbic acid and percentage crude protein accumulation of *Capsicum annuum*. The laboratory experimental results showed that seed germination and juvenile seedling growth of *C. annuum* were significantly retarded by both FSEM and FSET. The radicle growth was more susceptible to the phytotoxicity of both extracts than the plumule growth. Both plants extract had a concentration-dependent inhibitory effect on the seedling growth of the recipient crop while the FSET was more phytotoxic than FSEM. However, this retardatory effect of aqueous extracts on growth observed in the laboratory was reversed in the soil-cultured experiments such that application of FSEM significantly enhanced all the studied growth parameters (shoot height, number of leaves, leaf area, leaf area ratio, shoot fresh and dry weight, root fresh and dry weight, chlorophyll a, chlorophyll b, total chlorophyll, ascorbic acid content in the shoot and percentage crude protein in the shoot and

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fruits). Likewise, FSET application significantly increased the leaf area, total chlorophyll and percentage crude protein accumulation in the shoot and fruits of the recipient crop at P<.05. This study then emphasizes the fact that *T. rotundifolia* and *M. koenigii* are allelopathic plants. The increased ascorbic acid and percentage crude protein accumulation in the aqueous extract-treated crop could, apart from enhancing the nutritional benefits of the test crop, be an adaptive mechanism evolved by the crop to overcome the allelopathic stress posed by the application of the aqueous extracts. These findings therefore suggest that allelochemicals in the aqueous extract of *M. koenigii* and *T. rotundifolia* could serve as biofertilizers for boosting the production of *C. annuum*.

Keywords: Allelopathic; Murraya koenigii; Tithonia rotundifolia; Capsicum annuum; physiological; aqueous extract; ascorbic acid; crude protein.

1. INTRODUCTION

Plants often release metabolites that might be beneficial or detrimental to the growth of receptor plants in managed or natural ecosystems. This phenomenon is termed allelopathy. Allelopathy is a process that involves the transfer of secondary metabolites (allelochemicals) from the plant which produced them (donor) to another plant (receiver) whose growth and development become influenced by the allelochemicals it received [1,2]. Rizvi and Rizvi, [3] and Rice, [4] opined that allelopathy can be exploited to develop new crop management systems and improve existing ones. Chemicals with allelopathic potential are present in virtually all plants and in most tissues including leaves, stems, roots, flowers, fruits, buds, inflorescence, barks and seeds [5,6]. It is an established fact that some of the allelochemicals are water soluble and could be leached out of the plants during rainy season. These naturally occurring compounds play important roles in regulating plant biodiversity, dominance, succession and climax of natural vegetation, as well as in the productivity of agroecosystems. The application of correct concentration of allelochemicals in agricultural practice helps in increasing the agricultural productivity and reducing environmental hazards caused by the use of synthetic agrochemicals [7].

One of the donor plants in this study, *Tithonia rotundifolia* P.M. Blake of the family Asteraceae is a troublesome weed of arable fields. *T. rotundifolia* and *Tithonia diversifolia* are the only species of the genus *Tithonia*, found in Nigeria [8]. Both species share several similar reproductive, genetic, anatomical, morphological and physiological characteristics. In fact, recent phytochemical and phytotoxicity studies of *T. rotundifolia* species showed that aqueous extracts of this species contain allelochemicals and organic compounds similar to that of *T. diversifolia* [9]. However, the interference of *T. rotundifolia* on neighbouring plants has been scarcely studied unlike *T. diversifolia* whose allelopathic effects on growth, germination, pigment accumulation, ascorbic acid and protein contents of crops has been greatly explored [10,11,12,13,14].

Another donor plant in this study is *Murraya koenigii* L. commonly called “curry leaf”. *M. koenigii* of the family Rutaceae is an aromatic deciduous shrub, used as spice, flavouring agent and in conventional and traditional medicine to treat various ailments [15,16,17]. In addition to the similarity in the allelochemicals obtained from the aqueous extracts of *M. koenigii* and those present in many established allelopathic plants, it was recently observed that the growth of other plants seems hampered wherever *M. koenigii* grows. Hence, the interest to investigate the phytotoxic potential of its aqueous extract on *Capsicum annuum.*

Capsicum annuum L. is one of the four best known domesticated species of *Capsicum* in the world. It is a vegetable of northern Latin America origin. *C. annum* has become an important agricultural crop because of the economic importance and the nutritional value of its fruits [18,19]. The fruits are excellent source of natural colours and antioxidant compounds which when included in the human diet could serve as an important health-protecting factor [20]. *C. annuum* fruits also contain vitamin C, free radicals and other important organic compounds which chelate heavy metal ions and suppress peroxidation, thereby reducing the risk of arteriosclerosis, cardiovascular diseases and some forms of cancer in humans [21,22]. In view of the importance of *C. annum* to humans, this study was designed to investigate the effects of the aqueous extracts of *T. rotundifolia* and *M.*

koenigii on germination, growth and accumulation of photosynthetic pigments, ascorbic acid and crude protein of *C. annum.*

2. MATERIALS AND METHODS

2.1 Experimental Site and Materials Sources

The experiment was carried out at the Department of Botany, Obafemi Awolowo University (O.A.U.) Ile-Ife, Nigeria. The seeds of *C. annuum* and *T. rotundifolia* were collected from National Horticultural Research Institute (NIHORT) Ibadan and along Ede road, near the Obafemi Awolowo University (O.A.U.), Ile-Ife main campus gate respectively. Young seedlings of *M. koenigii* were collected at Road 22, Senior Staff Quarters of O.A.U. Ile-Ife.

2.2 Preparation of the Fresh Shoot Aqueous Extract

The extraction procedure followed that of Ahn and Chung [23]. Seventy-two gram (72 g) weighed fresh shoot of each of *T. rotundifolia* and *M. koenigii* were cut separately into small chips and finely crushed in a wet Philips (HR 2815i) kitchen blender. The blended plant material was soaked in 1Litre distilled water for 24 h. The solution was filtered through cheese cloth to remove debris and finally filtered using Whatman No. 1 filter paper. The final filtrate was considered to be the full strength (100%) of the extracts, i.e. 100% fresh shoot aqueous extract of *T. rotundifolia* (FSET) and 100% fresh shoot aqueous extract of *M. koenigii* (FSEM). One litre of each of the extract was diluted with equal volume of distilled water to obtain the 50% (v/v) or half strength of the extracts which were used in this study.

2.3 Seed Germination and Seedling Growth

C. annuum seeds were randomly selected for uniformity on the basis of size and soaked in 5% sodium hypochlorite for five minutes to prevent fungal growth. Thereafter, the seeds were rinsed in running tap water for 5 minutes and then thoroughly washed in double distilled water. Ten of these seeds were placed in each sterilized Petri-dishes lined with Whatman No 1 filter paper. The filter paper was moistened with 10 mL of the respective graded concentrations of fresh shoot aqueous extracts (100%, 50% FSET and 100%, 50% FSEM) for the treatment regimes and distilled water for the control. Each regime/treatment had six replicates. The Petri-dishes were incubated at room temperature (25°$\pm$2°C) for 14 days. Emergence of 1 mm of the radicle was used as the criterion for germination. Germination percentages were recorded while the radicle and plumule lengths were measured daily over 14 days of culture.

2.4 Soil Culture Experiment

Ten sterilized seeds of *C. annuum* were sown in each experimental pot (25 cm diameter × 9 cm depth) already filled with homogenous top humus soil and had six holes perforated at the bottom for good drainage. Each pot was irrigated with 300 mL of water on a daily basis for two weeks. Thereafter, the seedlings in each pot were thinned down to six uniform plants per pot. The pots were then allocated to the control and two different treatments; 100% fresh shoot aqueous extract of *T. rotundifolia* (100%FSET) and 100% fresh shoot aqueous extract of *M. koenigii* (100%FSEM). The experimental pots in the control regime were then supplied with 300 mL of water daily while the pots in the treatment regimes were supplied with 300 mL of the appropriate aqueous extract daily for six weeks. The pots were arranged in a complete randomized design. The zero day harvest of *C. annuum* took place just before the treatment started after which harvesting of the plants was done weekly for a period of six weeks. Data on the growth parameters (shoot height, stem girth, number of leaves was collected according to standard methods. The leaf area was determined following the method of Pearcy et al. [24] and the leaf area ratio calculated. Five shoots in each regime were weighed separately on a Mettler Toledo Balance to obtain the fresh weight. Each shoot was then packaged separately in envelopes and dried to constant weight at 80°C in a Gallenkhamp oven (Model IH-150) to obtain the dry weight. The chlorophyll content in the shoot was quantified following the procedure of Coombs et al. [25]. Ascorbic acid and protein contents were determined according to the titrimetric method and micro-Kjeldahl nitrogen method respectively as described by AOAC [26]. Ascorbic acid in the sample was calculated using the formula below:

$$\text{Ascorbic Acid in the Sample} = \frac{\text{X} \times \text{Y} \times \text{Titre of the Sample}}{\text{gram of the Sample}}$$

X is the ascorbic acid quantity equivalence of 1ml dichloro-indolephenol

Y is the ratio of the quantity (mL) of the extraction solution to the quantity (mL) taken for titration.

The percentage crude protein accumulation in the shoot of *C. annuum* was estimated using the formulae below.

$$\%\ Total\ Nitrogen\ in\ the\ Sample = \frac{(\mathrm{A}-\mathrm{B}) \times \mathrm{N} \times 14.01 \times 100}{\text{Milligram of the Sample}}$$

% Crude Protein = % Total Nitrogen × 6.25

A = sample reading, B = blank reading; N = Normality of acid used for titration,
100 = conversion to % and 6.25 is the correction factor (F)

2.5 Statistical Analysis

All experiments were conducted in five replicates and the data obtained were subjected to analysis of variance (ANOVA). Differences between individual means were determined by least significant difference (LSD) test at .05 level of probability. Data were analyzed using SPSS.

3. RESULTS

Table 1 shows the effect of the aqueous extracts of *T. rotundifolia* (FSET) and *M. koenigii* (FSEM) on the percentage germination, plumule and radicle length of *C. annuum*. From the table, the percentage germination of *C. annuum* seeds followed the trend; CONTROL>50%FSEM>50%FSET>100% FSEM>100%FSET indicating decrease in the germination percentage with increase concentration of the extracts. Hence, the highest and lowest germination percentage of *C. annuum* was recorded for the control and 100% FSET respectively. Statistically, percentage germination of *C. annuum* seeds in the control was significantly higher than that of the FSET and FSEM treated seeds at P<.05. This result shows that both FSET and FSEM contain allelochemicals capable of inhibiting the germination of *C. annuum* seeds. FSET was observed to be more phytotoxic to the germination of *C. annuum* seeds than FSEM.

The control seedlings had the longest radicle (4.0 cm) and plumule lengths (2.9 cm). The 50%FSET and 100%FSET were found to reduce the radicle extension to 55% and 10% while the plumule growth in these regimes respectively were likewise retarded to 82.8% and 55% of the control length. In the case of the seedlings grown in FSEM, the 50%FSEM were found to reduce, compare to the control values, the radicle and plumule extension to 50% and 62.1% respectively while 65% and 48.3% diminution in the radicle and plumule lengths respectively was observed for the 100%FSEM-treated *C. annuum* seedlings. The retardation of *C. annuum* seedling growth by different concentrations of FSET and FSEM also followed the trend 100%FSET> 100%FSEM> 50%FSEM> 50%FSET. Statistically, the radicle length of *C. annuum* was significantly retarded at P < .05 by half and full strength aqueous extracts of both donor plants while the plumule extension was significantly inhibited by full concentrations of the aqueous extract of donor plants only. This resultant trend of retardatory effect of both treatments (FSET and FSEM) showed that the radicle growth was more inhibited by the extracts compared to the plumule length.

Effects of the FSET and FSEM on the shoot height, shoot fresh and dry weight, root fresh weight and dry weight, number of leaves, leaf area and leaf area ratio of young *C. annuum* plants are shown in Tables 2-3. At P < .05, application of FSEM significantly increased all the studied growth parameters (shoot height, number of leaves, leaf area, leaf area ratio, shoot fresh and dry weight, root fresh and dry weight, chlorophyll a, chlorophyll b, total chlorophyll, ascorbic acid content in the shoot and percentage crude protein in the shoot and fruits). In the case of FSET application, only the leaf area of the recipient crop was significantly enhanced at P <.05.

Table 1. Effects of aqueous extract of *T. rotundifolia* and *M. koenigii* on germination, Plumule and Radicle lengths of *C. annuum*

Treatments	Germination (%)	LSD P<.05	Plumule length (cm)	LSD P<.05	Radicle length (cm)	LSD P<.05
CONTROL	43		2.9		4.0	
50%FSET	19	.003	2.4	.43	2.2	.046
100%FSET	4	.000	1.3	.005	0.4	.000
50%FSEM	21	.007	1.8	.08	2.0	.005
100%FSEM	18	.002	1.5	.02	1.4	.000

Table 2. Effects of fresh shoot aqueous extract of *T. rotundifolia* and *M. koenigii* on shoot height, number of leaves, shoot fresh and dry weights of *C. annuum*

Weeks of FSE application	Shoot height (cm)			Number of leaves			Shoot fresh weight (g)			Shoot dry weight (g)		
	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM
1	7.14	8.57	10.72	4.563	5.293	6.7525	1.723	2.462	3.323	0.055	0.073	0.015
2	8.22	11.79	15.00	4.928	7.300	8.3950	2.954	4.308	6.769	0.082	0.110	0.165
3	10.00	16.43	20.00	6.205	8.213	10.768	3.692	6.277	9.970	0.105	0.147	.224
4	11.07	17.86	29.65	7.300	9.855	14.783	5.046	8.123	11.077	0.115	0.197	.289
5	14.29	23.22	33.22	7.848	11.863	18.068	5.785	9.600	12.923	0.156	0.284	.362
6	15.72	25.72	37.51	8.943	12.958	20.075	6.893	11.57	13.662	0.174	0.353	.467
Grand Mean	11.07	17.27	24.35	6.631	9.247	13.140	4.349	7.057	9.621	0.114	0.194	.269
LSD P<.05		.17	.008		.23	.008		.16	.01		.20	.02

CTR means CONTROL experiment, FSET and FSEM mean Fresh Shoot aqueous extract of Tithonia rotundifolia and Murraya koenigii respectively

Table 3. Variations in the leaf area, leaf area ratio, root fresh and dry weights of *C. annuum* as influenced by the application of fresh shoot aqueous extract of *T. rotundifolia* and *M. koenigii*

Weeks of FSE application	Leaf area (cm^2)			Leaf area ratio			Root fresh weight (g)			Root dry weight (g)		
	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM
1	6.11	11.45	18.70	129.63	165.93	98.52	0.13	0.22	0.12	0.009	0.013	0.021
2	7.49	17.94	29.01	95.93	168.52	259.26	0.15	0.31	0.49	0.015	0.021	0.040
3	8.40	19.47	31.30	184.07	155.56	235.93	0.24	0.43	0.63	0.021	0.029	0.096
4	9.16	23.66	37.79	70.00	127.04	197.04	0.27	0.54	0.72	0.029	0.089	0.121
5	10.31	24.81	40.46	59.63	116.67	158.15	0.33	0.61	0.85	0.053	0.119	0.179
6	11.45	25.19	42.37	36.30	75.19	108.89	0.39	0.72	0.90	0.075	0.134	0.200
Grand Mean	8.65	20.42	33.27	95.93	134.82	176.30	0.25	0.47	0.62	0.034	.068	0.109
LSD P<.05		.004	.000		.23	.02		.09	.008		.29	.03

CTR means CONTROL experiment, FSET and FSEM mean Fresh Shoot aqueous extract of Tithonia rotundifolia and Murraya koenigii respectively

Table 4. Time course accumulation of chlorophyll a, chlorophyll b and total chlorophyll in *C. annuum*

Weeks of FSE application	Chlorophyll a (µM)			Chlorophyll b (µM)			Total Chlorophyll (µM)		
	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM
1	2.542	5.401	6.142	1.603	2.564	4.103	4.145	7.965	10.245
2	5.172	6.158	7.805	0.962	1.346	2.051	6.134	7.504	9.856
3	6.385	6.508	7.067	0.962	1.859	2.821	7.347	8.367	9.888
4	4.745	5.798	6.473	0.962	2.115	3.718	5.707	7.913	10.191
5	3.419	2.906	5.128	1.539	2.564	3.846	4.958	5.47	8.974
6	1.282	2.479	3.761	2.564	2.180	3.846	3.849	4.659	7.607
Grand Mean	3.924	4.875	6.063	1.432	2.105	5.096	5.356	6.98	11.159
LSD P<.05		.35	.045		.09	.000		.004	.000

CTR means CONTROL experiment, FSET and FSEM mean Fresh Shoot aqueous extract of Tithonia rotundifolia and Murraya koenigii respectively

Table 5. Time course accumulation of ascorbic acid and percentage crude protein in the Shoot and Fruits of *C. annuum*

Weeks of FSE application	Ascorbic Acid (mg/100 g)						Crude Protein (%)					
	In the shoot			In the fruits			In the shoot			In the fruits		
	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM	CTR	FSET	FSEM
1	0.119	0.220	0.189	0.560	0.250	0.420	7.606	18.028	14.930	0.750	0.750	2.850
2	0.062	0.330	0.282	0.990	0.720	0.810	3.099	32.958	19.463	1.020	1.020	3.500
3	0.150	0.436	0.348	1.250	0.980	1.060	11.268	23.944	19.718	1.560	1.560	5.900
4	0.189	0.299	0.510	1.720	1.180	1.240	15.493	25.070	19.718	1.980	1.980	9.250
5	0.220	0.282	0.458	1.900	1.560	1.360	10.141	24.225	21.408	2.350	2.350	11.500
6	0.238	0.290	0.400	1.600	1.560	1.640	9.296	25.352	32.958	2.810	2.810	14.050
Grand Mean	0.163	0.310	0.365	1.337	1.042	1.088	9.484	24.929	21.366	1.745	1.745	8.842
LSD P<.05		.01	.001		.31	.39		.000	.001		0.75	.006

CTR means CONTROL experiment, FSET and FSEM mean Fresh Shoot aqueous extract of Tithonia rotundifolia and Murraya koenigii respectively

Table 4 presents the time-course accumulation of chlorophyll a. chlorophyll b and total chlorophyll. Similar to the trend observed for the growth parameters, accumulation of chlorophyll a, chlorophyll b and total chlorophyll in *C. annuum* plants treated with FSEM was significantly higher than that of the control plants at $P < .05$ while such significant increase was observed only for the total chlorophyll accumulation in FSET-treated plant.

Evident from Table 5 is the fact that the application of the extracts of both donor plants (FSET and FSEM) resulted in significant increase in the percentage crude protein and ascorbic acid contents of the recipient plants shoot and fruits.

4. DISCUSSION

The aqueous extracts obtained from the shoot of *Tithonia rotundifolia* (FSET) and *Murraya koenigii* (FSEM) had varying degrees of inhibition on the germination and juvenile seedling growth of *C. annuum* seeds, reflecting the presence of allelochemicals which were detrimental to the growth of the germinating seeds in the applied extracts. Significant inhibition of seed germination at higher concentrations of FSET and FSEM may be due to allelochemicals in the extracts inhibiting the water uptake by the seeds as reported by Tawaha and Turk, [27]. Alternatively, it could be a net result of reduction in the level of gibberellic acid or alteration in the activity of gibberellic acid which is known to regulate de novo amylase production during germination process [28]. Also, the probable interference of allelochemicals with the cell division and elongation which are both growth prerequisite could perhaps explain the reduced radicle and plumule length recorded in the extract regimes. This finding is consistent with [9] who observed significant reduction in the percentage germination of *Sorghum bicolor* seeds treated with aqueous extract of *T. rotundifolia.* Similarly, [29] reported that aqueous extract of *M. koenigii* inhibited the germination and growth of radicle of mung bean. The phytotoxic effects of the aqueous extracts of donor plant species in this study were also found to be extract concentration dependent, a result that agrees with Lovett, [30] who stated that the response of the receiver plants to allelochemicals were often concentration dependent.

However, this inhibitory effect of aqueous extracts on growth observed in the laboratory was reversed on the field. The shoot height, shoot fresh and dry weight, number of leaves, leaf area, root fresh and dry weights of the treated plants were significantly enhanced by application of FSEM extracts at $p<.05$. Similar dual role (of inhibition in the laboratory and stimulation of growth on the field) had been reported for the aqueous extracts of *T. diversifolia* and *Chromolaena odorata* applied on *Vigna unguicuilata, Abelmuscus esculentus* and *Hibiscus sabdariffa* species [2,14]. Stark and Hyvarinen [31] opined that an important reason for such a reversal of response could be the role played by the soil microorganisms in detoxifying or utilizing the allelochemicals resulting in minimized plant to plant interference. According to Blum, [32], the bioactive concentration of allelochemicals leached into the soil is determined by the sorption, fixation, and chemical and microbial degradation or conversion. Hence, the enhancing effect of FSET and FSEM observed on the field could have resulted from the high rate of biodegradability, ephemerality and adsoptability of some phytotoxic allelochemicals in the humid tropics as well as the selective ability of recipient crops (*C. annuum* in this case) not to absorb and translocate phytotoxic active ingredients in the applied aqueous extracts. Tian et al. [33] reported that phytotoxic effect observed in the laboratory was not harmful to maize and cowpea growth under field condition because the phytotoxic compounds get rapidly degraded in the field than in the laboratory which resulted in a significant increase in maize and cowpea yield. This result further supports the findings of [14]. The authors adduced the enhancement of the growth of *Hibiscus sabdariffa* plants to the conversion of active phytotoxic allelochemicals in the extract of *T. diversifolia* to inactive absorbable or growth promoting forms by soil microbes. Similar results were obtained by [11,34].

The significant increase in the levels of biomolecules (chlorophyll, ascorbic acid and protein) accumulated in the shoot of aqueous extracts-treated *C. annuum* plants ~~over~~ compared to that of the control probably explain the radiant luxurious growth visually observed in extract-treated *C. annuum* plants compared ~~with~~ to the control plants. This geometric increase in the endogenous ascorbic acid contents and percentage crude protein of recipient plant was perhaps the allelopathic stress tolerance adaptive mechanism of the crop. Several authors have reported similar findings [2,35,36]. Furthermore, increased level of ascorbic acid

and crude protein percentage in the fruits of *C. annuum* plants subjected to extract-treatment indicates the capability of the aqueous extracts to effectively promote the growth of recipient crops up to the fruiting stage on the field, a result which corroborates the findings of Ogunwole et al. [37]. The significant increase in the accumulation of ascorbic acid and crude protein could be due to leaching of phytotoxic compounds in the applied extracts or their degradation by the soil microbes. Bearing in mind other factors, the enhanced ascorbic acid and percentage crude protein accumulation in the fruits of aqueous extract-treated *C. annuum* would improve both the antioxidants and nutritional values of the test crop. Similar results were obtained by [14,37].

5. CONCLUSION

The study showed that *Tithonia rotundifolia* and *Murraya koenigii* aqueous extracts contain allelochemicals which either directly or indirectly inhibit the germination and juvenile seedling growth in the laboratory while stimulating the growth of mature *C. annuum* plants on the field confirming that both plants are allelopathic plants. The aqueous extract of *T. rotundifolia* (FSET) was more phytotoxic to the germination and early seedling growth of *C. annuum* than that of *M. koenigii* (FSEM). In addition, the stimulation of *C. annuum* vegetative growth and accumulation of chlorophyll, ascorbic and percentage protein on the field could not have been induced solely by application of aqueous extract of *T. rotundifolia* or *M. koenigii* but might have been as a result of the synergy with the activities of soil microbes. This study also noted the accumulation of ascorbic acid and protein in the recipient crop which could be an adaptive mechanism evolved by the crop to surmount the allelopathic stress posed by the applied aqueous extracts. Further studies however need to be conducted to fully elucidate the mechanism of action of allelochemicals on receiver crops and the actual adaptive mechanisms evolved in the receiver crops to overcome the allelopathic stress.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. International Allelopathy Society. A science for the future. World Congress on Allelopathy, SAI University of Cadic publishers, Spain. 1996;1:10–30.
2. Taiwo LB, Makinde JO. Influence of water extract of Mexican sunflower (*Tithonia diversifolia*) on growth of cowpea (*Vigna unguiculata*). African Journal of Biotechnology. 2005;4(4):355-360. Available:http://www.academicjournals.org/AJB
3. Rizvi SJH, Rizvi V. Improving crop productivity in India – Role of allelochemicals. In: Waller GR, Editor. Allelochemicals: Role in Agriculture and Forestry. ACS Symposium Series, American Chemical Society, Washington. 1987;330:69-75. DOI: 10.1021/bk-1987-0330.ch007
4. Rice EL. Allelopathy: An overview. In: Waller GR, Editor. Allelochemicals: Role in Agriculture and Forestry. ACS Symposium Series, American Chemical Society, Washington. 1987;330:8-22.
5. Rice EL, Editor. Allelopathy. Academic Press, (NY). 1984;2:422.
6. Putnam AR, Tang C. The science of allelopathy. Wiley, (NY).
7. Farooq M, Bajwa AA, Cheema SA, Cheema ZA. Application of allelopathy in crop production. International Journal of Agriculture and Biology. 2013;15(6): 1367–1378. Available:http://www.republishers.org
8. Muoghalu JI, Chuba DK. Seed germination and reproductive strategies of *Tithonia diversifolia* (Helmsl.) A. Gray and *Tithonia rotundifolia* (P.M.) Blake. Applied Ecology and Environmental Research. 2005;3:39-46. ISSN: 1589 1623. Available:www.ecology.kee.hu
9. Otusanya OO, Ilori OJ. Phytochemical screening and the phytotoxic effects of aqueous extracts of *Tithonia rotundifolia* (P.M.) Blake. International Journal of Biology. 2012;4(3):97-101. DOI: 10.3923/rjes.2007.285.293
10. Ilori OJ, Otusanya OO, Adelusi AA. Physiological response of *Amaranthus cruentus* and *Oryza sativa* to phytotoxins of *Tithonia diversifolia*. Research Journal of Botany. 2007;2(1):23-32. DOI: 10.3923/riphyto.2007.12.20
11. Oyerinde RO, Otusanya OO, Akpor OB. Allelopathic effects of *Tithonia diversifolia* on the germination, growth and chlorophyll contents of maize (*Zea mays* L.). Scientific Research and Essays. 2009;4(12):1553-1558.

Available:http://www.academicjournals.org/SRE

12. Otusanya OO, Ilori OJ, Adelusi AA. Allelopathic effects of *Tithonia diversifolia* (Hemsl) A. Gray on germination and growth of *Amaranthus cruentus.* Research Journal of Environmental Science. 2007;1:285-293.
DOI: 10.3923/rjes.2007.285.293
13. Otusanya OO, Sokan-Adeaga AA, Ilori OJ. Allelopathic effect of the root exudates of *Tithonia diversifolia* on the germination, growth and chlorophyll accumulation of *Amaranthus dubius* L. and *Solanum melongena* L. Research Journal of Botany. 2014;9:13-23.
DOI: 10.3923/rjb.2014.13.23
14. Otusanya OO, Ogunwole AA, Tijani MO. Allelopathic effect of *Tithonia diversifolia* and *Chromolaena odorata* on the germination, growth and chlorophyll accumulation of Roselle (*Hibiscus sabdariffa* L.). International Journal of Botany and Research. 2015;5(3):1-14.
15. Gopalan C, Rama Shastri BV, Balasubramanian SC. Nutritive value of Indian foods. In: Nasaringa Rao BS, Deosthale YG, Pant KC, Editors. 2nd Ed. Indian Council on Medicinal Plant Research, New Delhi. 2011;4:66-117.
16. Satyavati GV, Gupta AK, Tandon SN, Seth SD. Medicinal plants of India. India Council of Medicinal Plant Research 1987;2:289-299.
Available:https://www.icmr.nic.in/content/medicinal-plants-india-vol2-1987-gv-satyavati-ashok-k-gupta-smt-neeraj-tandon-sd-seth
17. Arivoli S, Tennyson S. Studies on the mosquitocidal activity of *Murraya koenigii* (L.) Spreng (Rutaceae) leaf extracts against *Aedes aegypti, Anophele stephensi* and *Culex quinquefasciatus* (Diptera: Culicidae). Asian Journal of Experimental Biological Sciences. 2011;2: 721-730.
18. Esbaugh WH. History and exploitation of a serendipitious new crop discovery. In: Janick J, Simon JE Editors. New Crops. Wiley, NY. 1993;2:132-139.
Available:Https://hort.purdue.edu/newcrop/proceedings1993/v2-132.html
19. Navarro JM, Flores P, Garrido C, Martinez V. Changes in the contents of antioxidant compounds in pepper fruits at different ripening stages, as affected by salinity. Food Chemistry. 2006;96:66–73.
DOI: 10.1016/j.foodchem.2005.01.057
20. Howard LR, Talcott ST, Brenes CH, Villalon B. Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* species) as influenced by maturity. Journal of Agricultural and Food Chemistry. 2000;48(5):1713–1720.
DOI: 10.1021/jf990916t
21. Harris JR. Subcellular biochemistry; ascorbic acid biochemistry and biomedical cell biology. Plenum Publisher (NY). 1996;25. ISBN- 13: 978-1461379980, ISBN- 10: 1461379989.
22. Bramley PM. Is lycopene beneficial to human health. Phytochemistry. 2000;54: 233-236.
DOI: 10.1016/s0031-9422(00)00103-5
23. Ahn JK, Chung M. Allelopathic potential of rice hulls on germination and seedling growth of Barnyard grass. Agronomy Journal. 2000;92:1162–1167.
DOI: 10.2134/agronj2000.9261162x
24. Pearcy RW, Ehleringer JE, Monney HA, Rundel PW. Plant physiology and ecology - Field methods and instrumentation. Chapman and Hall Publisher (NY). 1989;423.
25. Coombs JH, Hall DO, Scurlock JMO. Biomass production and data. In: Coombs J, Hall DO, Scurlock JMO, Editors. Techniques in bio-productivity and photosynthesis. 2nd Ed. Pergamon International Library of Science, Technology, Engineering and Social Studies. 1985;2:274-287.
26. AOAC. Official methods of analysis 17th Edition. Association of Official Analytical Chemists, Washington, D. C., USA; 2000.
27. Tawaha AM, Turk MA. Allelopathic effects of black mustard (*Brassica nigra*) on germination and growth of wild barley (*Hordeum spontaneum*). Journal of Agronomy and Crop Science. 2003;189(5):298-303.
Available:https://doi.org/10.1046/j.1439-037X.2003.00047.x
28. Olofsdotter M. Allelopathic in rice. Proceeding of the Workshop on Allelopathy in Rice. International Rice Research Institute, Manila, Phillippinis. 1998;1–5.
DOI: 10.1111/j.1744-7348.2007.00183.x
29. Kakati B, Baruah A. Allelopathic effect of aqueous extract of some medicinal plants on seed germination and seedling length of

mung bean (*Vigna radiata* (L.) wilczek.). Indian Journal of Plant Sciences. 2013; 2(3):8-11.
Available:http://www.cibtech.org/ups.htm

30. Lovett JV. In. Chang-Hung C, Willer GR, Editors. Symposium on Phytochemical Ecology: Allelochemicals, Mycotoxins and Insect Pheromones and Allomones. Institute of Botany, Academia Sinica Publisher, Taipei, Taiwan. 1989;49-67.
31. Stark S, Hyvarinen M. Are phenolics leaching from the lichen *Cladina stellaris* sources of energy rather than allelopathic agents for soil microorganisms? Soil Biology and Biochemistry. 2003;35(10): 1381-1385.
Available:https://doi.org/10.1016/S0038-0717(03)00217-7
32. Blum U. Designing laboratory plant debris oil assays: Some reflections in principles and practices of plant ecology. In: Inderjit, Dakshini KMM, Foy CL, Editors. Principles and Practices in Plant Ecology: Allelochemical Interactions, CRC Press, Boca Ration, Florida; 1999.
33. Tian G, Kang BT, Brussard L. Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions–decomposition and nutrient release. Soil Biology and Biochemistry. 1992;24:1051–1060.
Available:https://doi.org/10.1016/0038-0717(92)90035-V
34. Aladejimokun AO, Edagbo DE, Adesina JM. Allelopathic potential of *Tithonia diversifolia* (Hemsl.) A. Gray on vegetative performance of cowpea and maize. Academia Arena. 2015;6(5):79-84. (ISSN 1553-992X).
Available:http://www.sciencepub.net/academia
35. Ambika SR, Poornima S. Allelochemicals from *Chromolaena odorata* (L.) King and Robinson for increasing crop productivity. In: Day MD, McFadyen RE, Editors. *Chromolaena* in the Asia-Pacific region, Australian Centre for International Agricultural Research, Canberra, Technical Reports. 2004;55.
Available:https://www.aciar.gov.au
36. Ogunwole AA, Otusanya OO. Interaction of aqueous extracts of *Tithonia diversifolia*, *Chromolaena odorata* and Kinetin induced growth and accumulation of chlorophyll in *Hibiscus sabdariffa* L. International Journal of Agriculture Innovations and Research. 2015;3(6): 1711-1720.
Available:https://ijair.org/index.php?option=com_jresearch&view=publication&task=show&id=546
37. Ogunwole AA, Otusanya OO, Oloyede FA, Tijani MO. Physiological response of *Hibiscus sabdariffa* to multi-year rainfall-leached allelochemicals of *Tithonia diversifolia* and *Chromolaena odorata*. International Journal of Science and Technoledge. 2015;3(12):61-71.
Available:http://internationaljournalcorner.com/index.php/theijst/article/view/124840

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/52891