ajfand SCHOLARLY, PEER REVIEWED AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT Volume 22 No. 3 April 2022 PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST ISSN 1684 5374

Afr. J. Food Agric. Nutr. Dev. 2022; 22(3): 19909-19928 https://doi.org/10.18697/ajfand.108.21455

POTENTIAL SUPPRESSIVE EFFECTS OF MEXICAN POPPY WEED RESIDUES ON GERMINATION AND EARLY GROWTH OF MAIZE AND PEARL MILLET CROPS

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ABSTRACT

Argemone ochroleuca allelochemical properties have been reported but not empirically tested on economically important staple cereal crops. Therefore, the objective of this study was to determine the potential Allelopathic effects of the alien weed's residues on germination and early-growth of maize (*Zea mays L.*) and Pearl millet (*Pennisertum glaucum*). Allelopathic effects of *A. ochroleuca* on maize and millet seed germination were tested in a 2 (shoot and root) x 11 (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100g/L water) factorial treatment arrangement in CRD in an incubator placed in a laboratory. Whereas effects of the weed extracts on the same crops' early-growth were tested in a 2 (shoot and roots) x 8 (0, 2, 4, 6, 8, 10, 12 and 14g ground-powdered extracts) factorial arrangement in RCBD under laboratory conditions. Maize and millet germination percentage, germination speed, mean germination time, mean daily germination, plumule and radicle length were measured for germination test, whereas, plant height, stem diameter, root and shoot mass were used as indicators of *A. ochroleuca* suppression of early plant growth. Relative to untreated control, concentration equal to and greater than 10g/L aqueous extracts of *A. ochroleuca* reduced millet and maize seed germination variables by 10–100% and 28–56%, respectively, while early-growth variables were reduced by 66–100% and 4–37%, respectively. *Argemone ochroleuca* shoot extracts were more suppressive than root extracts on germination and early growth of the two crops. In conclusion, *A. ochroleuca* Allelopathic effects were concentration and plant-part dependent, inhibitory effects increased with concentrations, with extracts from shoots being more Allelopathic on measured variables when compared to root extracts. As *A. ochroleuca* continues to spread yearly without any control strategies in place, a threat exist on maize and Pearl millet production especially in communal farming areas where improved management strategies are non- existent.

Key words: Allelopathic, *Argemone ochroleuca*, germination, growth, millet, maize, plumule, radicle

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INTRODUCTION

Cereal crops are the main grain food crops in the world, providing staple diets in most developing countries [1]. About 50% of the world daily caloric intake is obtained from the consumption of these crops [2]. Maize (*Zea mays L.*) and Pearl millet (*Cenchrus americanus/ Pennisetum glaucum (L.) Morrone*) are reliable nutritious sources of food for human and animal consumption throughout Southern Africa, due to their adaptability to a wide range of agro-ecological zones and contribution to sustainable food security [3]. Weeds are a major challenge in cereal production with reported worldwide yield losses estimated at 10.5 % [4, 5, 6]. The success of most cereal crop production enterprise relies on the proper management strategies of pests such as weeds without causing harm to the environment [7].

Most weeds deploy a multipronged approach in their competition with crops, including rapid emergence and establishment [8], widely distributed viable seed bank that can survive for many years [9], well developed rooting system and canopy that enables them to outcompete crops for water, nutrients and light [10], production of allelochemicals that suppress germination and growth of crops [11].

Mexican prickly poppy (*Argemone ochroleuca)* weed has been reported as an invasive alien noxious weed that possess a new threat to agro-ecosystem diversity in semi-arid and arid regions of Africa, Asia and Australia [8]. The competitive edge of Mexican poppy weed has been linked with the release of allelochemicals with potential to impede germination and vigour of seedlings of numerous crops and several vegetables [12]. The mechanism of allelochemicals on crops has been associated with the chemicals' ability to negatively affect enzymes required for germination, impeding radicle growth, inflammation of root tips resulting in absence of root hairs, and low reproductive capacity of affected crops [13]. Namkeleja *et al*. [12] reported a decline in seed germination percentages of the *Brachiaria dictyoneura* and *Clitoria ternatea* exposed to seed and leaf aqueous extracts of *A. ochroleuca*. The germination suppression as high as 100% has been observed due to *A. ochroleuca* extracts on wild range plant species and forage crops, with sensitivity to allelochemicals varying with plant species [9]. Greater than 50%, concentration dependent reductions in germination and seedling growth of different sorghum (*Sorghum bicolor* (L.) Moench) varieties has also been reported due to *A. ochroleuca* extracts [14]. This was in conformity with observation made by Alagesaboopathi [15] were another invasive alien species, *A. mexicana*, inhibited seed germination, plumule length, radicle length, fresh and dry weight of *Sorghum bicolor*.

Argemone ochroleuca management has many challenges, including that the weed is unpalatable and poisonous to animals suggesting it cannot be controlled effectively by animal grazing [9]. The presence of thorny vegetative shoots makes it difficult to handle the weed in manually weeded cropping systems. This results in most resource-poor communal farmers dependent on hand weeding, leaving the weed residues to decompose in the field [16], a practice that causes allelochemical released from the weed to be incorporated into the soil, affecting the next crop. The phytotoxicity of *A. ochroleuca* on germination and growth of maize and Pearl millet has not been

extensively investigated. The objective of this study was, therefore, to determine the effects of aqueous water extracts of *A. ochroleuca* on germination and early seedling growth of maize and Pearl millet.

MATERIALS AND METHODS

Description of study area

The study was conducted at the University of Mpumalanga (25.4365° S, 30.9818° E), South Africa, under laboratory and greenhouse conditions.

Preparation of the aqueous water extract

Mature plants of the *A. ochroleuca* were collected from the University of Mpumalanga farm. The plants were separated into individual parts, roots, and shoots, before being washed thoroughly with distilled water to remove any soil material. The collected roots and shoots of *A. ochroleuca* were oven dried at 55 ℃ for 72 hours before being ground and sieved through a 2 mm sieve into a conical flask. A 100 g sample of each plant part was then separately mixed with 1000 ml of boiling deionised water and left for 24 hours to allow extraction of phytochemicals into the water [17]. A funnel with a cotton at the bottom were then used to separate the solid plant residues and aqueous water extracts. The resultant aqueous extracts were 100 g/L deionized water. A treatment consisting of deionised water only was included as a control [12].

Effects of *Argemone ochroleuca* water extracts on seed germination

The effects of *A. ochroleuca* aqueous extracts on germination of maize and Pearl millet seeds were determined under laboratory conditions. Two laboratory experiments were conducted, one for maize and the other millet. Each experiment was laid-out in a complete randomized design with a 2 x 11 factorial treatment arrangement. First factor consisted of two plant parts, shoot and roots, whereas the second were extract concentrations of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100g/L de-ionized water applied as seed germination treatments. Each treatment was replicated three times (n = 66). Ten seeds were placed in 9-cm diameter petri dishes lined with a double layer of sterilized Whatman No1 filter paper for each experimental unit. The seeds were treated with 10 ml of *A. ochroleuca* aqueous extract of respective treatment using a syringe on a daily basis. The seeds treated with distilled water only were considered as a control. The petri dishes were placed in an incubator set at 25 ℃. Germination tests were conducted following the seed germination test guidelines proposed by the International Seed Testing Association [18]. Three independent trials for each experiment were conducted to validate the results.

Data collection on germination variables

The number of germinated seeds were recorded daily for seven days. The seeds were considered germinated when plumule and radicle were 2 mm long and did not have any abnormalities, a sign that the seedling will grow into a normal plant under normal conditions. After 7 days of incubation final germination record was taken together with measurement of radicle and plumule lengths. Germination percentage, germination speed, mean germination time and mean daily germination were computed using the formulae [19]:

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$$Germination\ percentage = \frac{number\ of\ germinated\ seeds\ in\ each\ petri\ dish}{total\ number\ of\ seeds\ in\ each\ petri\ dish}\ x\ 100$$

$$Germination\ speed = \frac{n1}{d1} + \frac{n2}{d2} + \frac{n3}{d3} \pm - - - - \frac{n7}{d7}$$

$$Mean\ germination\ time = \frac{\text{n1 x d1} + \text{n2 x d2} + \text{n3 x d3} + - - - - \text{n7 x d7}}{Total\ number\ of\ days}$$

Where n = number of germinated, seed d = number of days

$$Mean\ daily\ germination = \frac{Total\ number\ of\ seeds\ germinated}{Total\ number\ of\ days}$$

Effects of *Argemone ochroleuca powder* extracts on early plant growth

Argemone ochroleuca plants were harvested and prepared as stated above, except that the powders were used instead of water extracts. Twenty-five-centimeter diameter pots were filled with sandy loam soil laced with respective A. ochroleuca powders thoroughly incorporated into the top 5 cm soil layer of each pot. Four seeds of maize or millet were planted in each pot. In each experiment, the seedlings were considered emerged if two healthy true leaves had formed, an indication that it would grow into a normal plant under normal conditions. Two greenhouse pot experiments involving maize and millet planted in *A. ochroleuca* powder mixed soil medium were laid-out in a randomized complete block design. The two experiments of 2 x 8 factorial arrangements were replicated three times (n = 48). The first factor consisted of source of *A. ochroleuca* powder extracts (shoots and roots) and second factor were masses of powdered extracts at 8 treatment levels of 2, 4, 6, 8, 10, 12 and 14 g per pot. The pots that had no *A. ochroleuca* powder were considered as control.

Data collection on growth variables

Thirty days after emergence, plant height, stem diameter, root and shoot masses were measured. Plant height measurements were taken from the soil surface to the tip of the flag leaf. Destructive sampling was done by cutting stems at the soil line interface and stem diameter measured at 5 cm above the severed ends using a digital Vernier calliper. Root systems were removed from pots, immersed in water to remove soil particles before blotting them dry using a paper towel. Shoots and roots were oven-dried at 70 °C for 72 hours and weighed.

Statistical analysis

The collected data were subjected to analysis of variance using Statistix 10 software. The normality of the residual distribution was tested using the Shapiro-Wilk test [20]. The data which were not normally distributed ($P \leq 0.05$) were transformed using $arcsine\ \sqrt{(x \div 100)}$ for percentage data and $Log_{10}(x+1)$ for the rest [21]. Means of statistically significant variables were separated using Fisher's least significance difference (LSD) test at 5 % probability [21]. Relative impacts (RI %) of treatments relative to control were computed using formular = [(treatment/control) – 1] *100.

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RESULTS AND DISCUSSION

Shapiro-Wilk test for normality revealed that all Pearl millet germination and growth variables and all maize germination variables were not normally ($P \leq 0.05$) distributed hence, were transformed accordingly. While data for all maize growth variables were normally distributed ($P \geq 0.05$), except for the number of leaves. There were also no significant ($P \geq 0.05$) differences between the three independent germination trials, hence, the data were pooled and reanalysed as one set.

Allelopathic effects of *Argemone ochroleuca* extracts on Pearl millet and maize germination

The first order interaction of *A. ochroleuca* source of extracts (shoots and roots) and concentration of extracts were not significant ($P > 0.05$) for all Pearl millet and maize germination variables, except for Pearl millet germination speed (Table 1 and 4). Concentrations of *A. ochroleuca* extracts were highly significant ($P \leq 0.05$), for Pearl millet germination percentage, mean germination time and mean daily germination whereas, plant part source of extract was not significant ($P > 0.05$).

Generally, as concentrations of *A. ochroleuca* aqueous extracts increased the Pearl millet germination variables decreased (Table 1 and 2). Aqueous shoot extracts of *A. ochroleuca* reduced Pearl millet germination speed by 25–86% at concentrations of 40 g/L water and above, whereas root extracts reduced germination speed by 33–82% at concentrations of 30 g/L water and above relative to control (Table 1). Concentrations of *A. ochroleuca aqueous extracts* (≥ 20 g/L) reduced Pearl millet germination percentage, and mean germination time by 30–75% and 19–78%, respectively, whereas concentrations of 30 g/L and above reduced mean daily germination by 24–67% when compared to the control (Table 2).

Both plant part and concentration were highly significant ($P \leq 0.05$) for maize germination percentage, mean germination time and mean daily germination. As concentrations of *A. ochroleuca* aqueous extracts increased the germination variables decreased (Table 4). Extract concentration of 30 g/L and above reduced germination percentage, germination speed, mean germination time and mean daily germination of maize by 43–56, 28–50, 29–47 and 29–44 %, respectively (Table 4).

The current study reports on the suppressive allelopathic effects of aqueous extracts of the *A. ochroleuca* on germination and growth variables of maize and Pearl millet. The allelopathic effects were plant, concentration and organ depended. Pearl millet was more sensitive than maize with germination variables reduced by between 25–100% compared to 28–56% in maize, while the growth variables of Pearl millet were reduced by between 66–100% compared to 21–50 % for maize. Baličević *et al.* [22] reported that the aqueous extracts of *Solidago gigantea* had allelopathic effects on germination of carrot, barley, and coriander. Furthermore, germination of *Abutilon theophrasti* and *Amaranthus retroflexus* was inhibited significantly by all the concentrations of *Solidago gigantea*. Szabó *et al*. [23] also observed reduction in the germination of maize by all extract concentrations of *Amaranthus retroflexus.*

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The plant specific effects were also reported on *Farsetia aegyptia, Salvia aegyptiaca*, *Hordeum vulgare* and *Medicago sativa* when exposed to extracts of *A. ochroleuca* and reported that *F. aegyptia* was highly sensitive to weed extracts while *H. vulgare* had the least [9]. Many researchers [24] have reported the genetic variations in response to the allelochemicals. The reasons surrounding these differences in plant response to the same allelochemicals is less studied hence, less understood [27] even though most research agrees that it is due to differences in physiological and morphological characteristics of target plants [26]. Tejeda-Sartorius *et al*. [25] explained that the increased suppression of radish seed germination compared to onion and carrots by amaranth extracts is because of the presence of the allelochemicals during the critical stages of germination when compared to the other vegetables' physiological differences between the crops. Nikneshan *et al*. [26] interpreted the differences in germinations as due to differences in outer seed shells. In the current study, the difference is hypothesised to be due to differences in size of the two cereals hence their surface areas for the absorption of allelochemicals. Since several allelochemicals target the antioxidant systems in the target plant resulting in increased permeability of the cell membranes [26]. Furthermore, previous studies have shown that maize consumes more water compared to Pearl millet and Sorghum.

The study also observed a concentration-dependent and plant-part-dependent response of Pearl millet and maize germination, with higher extract concentrations having higher suppressive effects that lower concentrations. Also extracts from shoots had more allelopathic effects when compared to root extracts. Dar *et al*. [9] observed increased suppression of wild range species and fodder crops germination to increase *A. ochroleuca* concentrations. Alagesaboopathi [15] speculated that allelochemicals such as alkaloids, glycosides, saponins, tannins and flavonoids in *A. mexicana* extracts could be associated with decreased germination of sorghum plants and increasing the concentrations increased the levels of inhibitory chemicals. Namkeleja *et al.* [12] reported an increase inhibition of *Brachiaria dictyoneura* and *Clitoria ternatea* germination by high concentrations of *A. mexicana* than lower concentrations. Devi *et al.* [29] made similar observations of the decrease in germination of maize seeds with increase in the concentration of Parthenium extracts.

There are variations in types and concentrations among different plant organs [12, 30]. Rajendiran [31] reported that allelochemicals were in high concentrations in some plant parts than others, these chemicals had the ability to prevent seed embryo from growing or could kill it and the aqueous extracts of *Parthenium hysterophorus* led to several chromosomal aberrations in dividing cells which could be due to the increase in allelochemical concentrations. Shoot extracts of *A. ochroleuca* had higher inhibitory effects on germination of fodder plants when compared to root extracts [9]. This is similar to the observation made in this study where shoot extracts had more inhibitory effects on germination of both Pearl millet and maize seeds. Baličević *et al.* [32] reported a higher reduction of maize seed germination by shoot extracts of *Convolvulus arvensis* compared to other extract source plant parts. This was concurring with work by Shahrokhi *et al.* [33] who observed that bindweed water extracts from shoots reduced germination percentage of barley seeds more than other organs. Rajendiran

[31] reported that the extracts made from leaves of *Parthenium hysterophorus* affected germination compared to extracts made from the stems.

The interaction between concentration and plant part of *A. ochroleuca* factors were highly significant for both radicle and plumule in Pearl millet (Table 1), whereas in maize the interaction was highly significant for radicle length but not significant for plumule length (Table 4 and 5). Extract concentrations of 30 g/L and above made from shoots reduced Pearl millet plumule length by 33–100% and those of 10 g/L and above made from roots reduced it by 42–95%, relative to control (Table 1). The shoot extracts at 20 g/L and above reduced Pearl millet radicle length by 28–100%, whereas concentrations of 10 g/L and above root extracts reduced radicle length by 56–100% (Table 1). Concentration of *A. ochroleuca* root extracts reduced radicle length by 41–76 %, whereas shoot extracts reduced the same variable by 23–89% at extract concentrations of 10 g/L and above (Table 6). As concentrations of *A. ochroleuca* extracts increased from 10 g/L they reduced maize seedling plumule length by 16–65% relative to the control (Table 4). The *A. ochroleuca* extracts from shoot had higher suppressive effects on maize plumule length than extracts from roots (Table 5).

In the current study the concentrations and plant parts of *A. ochroleuca* had a negative effect on the length of the radicle and plumule of maize and millet seedlings. The observations made in this study are in conformity with Joshi and Joshi [34] who reported that the plumule and radicle growth and development are sensitive to allelochemicals, when they were decreased by extracts from *Alternanthera sessilis, Malachra capitata* and *Ipomoea carnea*. Devi *et al*. [29] also reported that the plumule length was suppressed as concentrations of Parthenium increased. Findings in this study support observations made by Al-Zahrani and Al- Robai [35] when growth of the radicle of barley and wheat unaffected in both low and high concentrations. However, growth significantly decreased as the concentrations of leaf extracts increased. This current study also reports of the different effects of the aqueous extracts of *A. ochroleuca* made from shoots had more effect on radicle and plumule length of maize and millet crops than those made from roots. The shoot aqueous extracts of *A. ochroleuca* had more effect on the radicle length than the plumule length. El-Darier and Yousef [36] made similar observations of negative correlation between different concentrations of alfalfa on plumule and radicle length of *Lepidium sativum*. Allelochemicals present in the aqueous extracts of *Calotropis procera* had more effect on the radicle length than the plumule length. According to Al-Zahrani and Al- Robai [35] roots absorb the allelochemicals first before the plumule, which causes the radicle to be more sensitive to the allelochemicals present in the aqueous extracts of *Calotropis procera*.

Allelopathic effects of *Argemone ochroleuca* extracts on Pearl millet and maize seedling early growth

The interaction between concentration and plant part were highly significant for plant height, number of leaves and dry root mass, but not significant for stem diameter and dry shoot mass in Pearl millet while in maize the interaction was highly significant for plant height, number of leaves, dry root and shoot masses, but not significant for stem diameter (Table 6). Both plant source and concentration of the extract as individual

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factors were also not significant ($P \geq 0.05$) for stem diameter and dry shoot mass of millet seedlings whereas plant part factor was highly significant ($P \leq 0.05$) for maize stem diameter, while application level was not significant for the same variable (Table 5).

In Pearl millet, *A. ochroleuca* root extract level of 14 g only was able to reduce plant height, number of leaves and dry root mass by 66, 71 and 83%, respectively, while only 2 and 4 g of shoot extracts reduced the same variables both by 100% (Table 3). Maize plant height was reduced by the *A. ochroleuca* root extract levels of 8, 12 and 14g but increased by shoot extract level of 12g with all other shoot extracts levels not having an effect (Table 6). The dry root mass of maize seedlings was reduced by *A. ochroleuca* root extracts of 6, 12 and 14 g and shoot extracts of between 6 and 10g (Table 6). Number of maize seedling leaves were not affected by *A. ochroleuca* root extracts but increased by shoot extracts while both *A. ochroleuca* root and shoot extracts did not affect seedling dry shoot mass (Table 6). Seedlings exposed to *A. ochroleuca* shoot extracts had greater stem diameters than those treated with root extracts (Table 5).

In the current study, the *A. ochroleuca* extract levels and plant part source had varying effects on growth variables of Pearl millet and maize. Like in the germination experiments, the negative allelopathic effects were plant, concentration and organ depended. In Pearl millet all growth variables were generally inhibited by increasing weed extracts application levels. Similar observations were made by Khan *et al*. [37] who reported that concentrations of *Sorghum halepense* L., *Trianthema portulacastrum L*., *Parthenium hysterophorus* L. and *Xanthium strumarium* L aqueous extracts had significant inhibitory effects on the plant height and dry biomass of the maize cultivars and as concentration of *S. halepense* L., *T. portulacastrum L*., *P. hysterophorus* L. and *X. strumarium* L increased, plant height and dry shoot mass and roots decreased. The observations are in conformity also with Szabó *et al.* [23] who reported that the dry weight of maize plants was reduced by allelochemicals. Siyar *et al*. [38] had similar observations were wheat dry weight decreased as the concentrations of *Avena fatua, Phalaris minor* and *Chenopodium album* aqueous extracts increased. According to Verma and Rao [39] who reported that the allelochemicals present in the extracts of *Ageratum conyzoides* and *Parthenium hysterophorus* mainly phenolics and other several secondary metabolites such as toxins, growth regulators, vanillic, alkaloids, identified gallic, p-hydroxybenzoic acids and terpenoids could inhibit seedling growth of soyabean (*Glycine max (L.) Merrill).*

Maize plants exposed to increasing application levels of *A. ochroleuca* demonstrated both inhibitory and stimulatory effects depending on the plant part measured and the source of the plant from where the extract is obtained. Maize seedling plant height were reduced by *A. ochroleuca* extract from the roots but stimulated by shoot extracts. Maize seedling root mass was reduced by both root and shoot extracts whereas, the number of leaves were stimulated by shoot extracts with roots having no effect on the variable. The seedling dry shoot mass was not affected by both root and shoot extracts. Bashir *et al*. [24] reported that the variation in effects of these variables has been observed previously and demonstrated variation in growth variable response of different varieties of rice and wheat to sunflower allelopathic residues. Furthermore, High suppressive

effects of germination and lower effects on growth variable observed in this study were also observed previously and there has been reports that seed germination is highly sensitive to allelochemicals than growth variables [24]. The surprising stimulative effects of some variables even though rare have also been observed previously [30, 40]. Dube *et al*. [40] also reported differences plant parts have different growth-dependent responses to phytochemicals.

CONCLUSION

In conclusion, the study makes a report of the suppressive allelopathic effects of aqueous water extracts of *A. ochroleuca* on germination, length of plumule and radicle as well as early growth of maize and Pearl millet. The negative allelopathic effects were greater on seed germination than seedling growth. The responses also varied between the two crops and were concentration, plant part dependent. Generally, shoot extracts were more inhibitive of germination variables and growth variables, compared to root extracts and lower concentrations had lower inhibitory effects on measured variables, while higher concentrations had higher effects. Moreover, *Argemone ochroleuca* continues to spread yearly without any control strategies in place, and it poses a threat on maize and Pearl millet production. Therefore, it is crucial to control any infestations of the Argemone ochroleuca at an early stage, to prevent the weed from causing a decline in the yield of the crops.

ACKNOWLEDGEMENTS

The University of Mpumalanga provided financial support and equipment for this study

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Table 1: Interactive effect of *Argemone ochroleuca* plant parts and extract concentration on germination speed, plumule and radicle length of pearl millet

Concentration (g/l)	Plant parts											
	Germination speed				Plumule length (mm)				Radicle length (mm)			
	Roots	R.I[y]	Shoots	R.I[y]	Roots	R.I[y]	Shoots	R.I[y]	Roots	R.I[y]	Shoots	R.I[y]
0	0.36 (12.40)^{abc}	-	0.37 (13.32)^{ab}	-	1.23 (30.98)^{ab}	-	1.26 (30.57)^{a}	-	1.39 (47.63)^{a}	-	1.33 (37.97)^{a}	-
10	0.29 (8.26)^{bcdef}	-19	0.39 (14.34)^{a}	4	0.72 (13.83)^{def}	-42	1.35 (32.17)^{a}	7	0.61 (9.60)^{c}	-56	1.28 (30.70)^{a}	-4
20	0.26 (6.67)^{defg}	-27	0.34 (10.98)^{abcd}	-10	0.58 (9.80)^{efg}	-53	1.11 (31.60)^{abc}	-12	0.18 (2.87)^{def}	-87	0.96 (18.20)^{b}	-28
30	0.24 (5.78)^{efgh}	-33	0.31 (9.20)^{bcde}	-18	0.51 (5.60)^{fgh}	-59	0.85 (20.80)^{cde}	-33	0.56 (0.43)^{c}	-60	0.07 (6.30)^{ef}	-95
40	0.16 (2.66)^{hijk}	-55	0.25 (6.37)^{defgh}	-33	0.19 (2.40)^{ijk}	-84	0.96 (25.53)^{bcd}	-24	0.00 (0.00)^{f}	-100	0.66 (7.57)^{c}	-50
50	0.17 (3.55)^{hij}	-54	0.18 (3.19)^{ghij}	-53	0.31 (5.33)^{ghij}	-75	0.34 (7.50)^{ghij}	-73	0.06 (0.433)^{ef}	-100	0.20 (1.40)^{de}	-85
60	0.21 (4.30)^{fghi}	-42	0.28 (7.96)^{cdef}	-25	0.31 (3.83)^{ghij}	-74	0.72 (17.13)^{def}	-43	0.00 (0.00)^{f}	-100	0.29 (2.00)^{d}	-78
70	0.17 (3.02)^{hij}	-54	0.14 (2.12)^{ijkl}	-61	0.24 (3.27)^{hijk}	-81	0.28 (4.03)^{hijk}	-78	0.00 (0.00)^{f}	-100	0.09 (0.47)^{def}	-93
80	0.14 (2.12)^{ijkl}	-60	0.10 (1.59)^{jklm}	-73	0.16 (1.87)^{ijk}	-87	0.07 (0.57)^{jk}	-95	0.00(0.00)^{f}	-100	0.06 (0.33)^{ef}	-95
90	0.06 (0.73)^{lm}	-82	0.05 (0.48)^{m}	-86	0.06 (0.57)^{jk}	-95	0.00 (0.00)^{k}	-100	0.00 (0.00)^{f}	-100	0.00 (0.00)^{f}	-100
100	0.21 (5.08)^{efghi}	-40	0.07 (0.65)^{klm}	-80	0.43 (5.33)^{fghi}	-65	0.08 (1.47)^{jk}	-94	0.00 (0.00)^{f}	-100	0.02 (0.07)^{ef}	-99
P-value	0.0349				0.0000				0.0000			
$LSD_{0.05}$	0.0916				0.2935				0.1988			
F-value	2.22				5.54				9.35			

[x]Column means followed by the same letter are not significantly different at $P \leq 0.05$. According to Fisher's least significant difference. [y]Relative Impact = [(treatment/control) – 1] *100. Values in brackets are none transformed

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Table 2: Effects of *Argemone ochroleuca* concentrations on germination percentage (GP) mean germination time (MGT) and mean daily germination (MDG) of Pearl millet seeds

Conc. (g/L)	GP	R.I (%)[y]	MGT	R.I (%)[y]	MDG	R.I (%)[y]
0	1.26 (88.33)[a]	-	0.59(31.69)[a]	-	0.11 (1.26)[a]	-
10	1.10 (75.00)[ab]	-13	0.55(27.88)[ab]	-7	0.10 (1.07)[ab]	-8
20	0.88 (58.33)[bc]	-30	0.48 (21.86)[bc]	-19	0.09 (0.83)[abc]	-20
30	0.80 (51.67)[cd]	-36	0.45 (19.29)[bc]	-24	0.09 (0.73)[bcd]	-24
40	0.55 (28.33)[def]	-56.	0.37(10.93)[de]	-45	0.06(0.40)[defg]	-45
50	0.47 (21.67)[ef]	-62	0.28 (8.31)[ef]	-54	0.05(0.31)[efg]	-52
60	0.66 (38.33)[cde]	-47	0.39 (14.93)[cd]	-35	0.07 (0.55)[cde]	-36
70	0.41 (16.67)[ef]	-68	0.25 (6.38)[ef]	-59	0.05 (0.24)[efg]	-58
80	0.32 (11.67)[f]	-75	0.19 (4.50)[fg]	-68	0.04 (0.17)[g]	-67
90	0.41 (23.33)[ef]	-67	0.13 (2.95) [g]	-78	0.04 (0.33)[fg]	-62
100	0.62 (35.33)[cdef]	-51	0.27(8.70)[ef]	-55	0.06 (0.51)[cdef]	-43
P value	0.0000		0.0000		0.0000	
$LSD_{0.05}$	0.2936		0.1104		0.0257	
F-value	8.52		15.9		7.75	

[x]Column means followed by the same letter are not significantly different at $P \leq 0.05$ according to Fishers least significant difference. [y]Relative Impact = [(treatment/control) – 1] *100. Values in brackets are none transformed

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Table 3: Interactive effect of *Argemone ochroleuca* plant part and application level on plant height, number of leaves and dry root mass of Pearl millet seedlings

Powder (g)	Plant parts											
	Plant height (cm)				Number of leaves				Dry root mass(g)			
	Roots	R.I (%)[y]	Shoots	R.I (%)[y]	Roots	R.I (%)[y]	Shoots	R.I (%)[y]	Roots	R.I (%)[y]	Shoots	R.I (%)[y]
0	2.13 (138.4)[ab]	-	2.20(160.9)	-	0.55(2.58)[a]	-	0.51(2.23)[ab]	-	3.42(7.90) [ab]	-	2.90 (6.70) [ab]	-
2	1.84 (76.67)[ab]	-14	0.00(0.00)[c]	-100	0.56(2.67)[a]	1	0.00(0.00)[d]	-100	2.24(5.18) [abcd]	-35	0.00(0.00)[e]	-100
4	2.20 (159.2)[a]	3	0.000(0.00)[c]	-100	0.45(1.83)[abc]	-18	0.00(0.00)[d]	-100	1.70(3.93) [abcde]	-50	0.00(0.00)[e]	-100
6	1.42 (91.43)[abc]	-33	1.58(165.3) [ab]	-28	0.30(1.22)[abcd]	-46	0.32(1.33)[abcd]	-37	6.35(1.46) [de]	-81	3.05(7.07)[ab]	5
8	2.11 (129.5)[ab]	-1	0.75(59.0)[bc]	-66	0.51(2.21)[ab]	-8	0.20(1.00)[bcd]	-60	2.03(4.68) [abcde]	-41	1.23(2.83)[bcde]	-56
10	1.32 (62.67)[abc]	-38	1.53(131.9)[ab]	-31	0.31(1.28)[abcd]	-44	0.32(1.33)[abcd]	-37	8.60(1.98) [cde]	-75	1.60(3.60)[abcd]	-46
12	2.09 (151.3)[ab]	-2	2.28(190.3)[a]	3	0.50(2.17)[ab]	-10	0.48(2.00)[abc]	-6	1.78(4.12) [abcde]	-48	3.55(8.22)[a]	22
14	0.73 (50.23)[bc]	-66	1.55(141.0)[ab]	-30	0.16(0.67)[cd]	-71	0.36(1.67)[abc]	-29	5.68(1.31) [d]	-83	1.7(4.0)[abcde]	-40
P-value			0.0308				0.0235				0.0484	
$LSD_{0.05}$			0.7013				0.1590				1.096E-03	
F-value			2.59				2.75				2.33	

[x]Column means followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's least significant difference. [y]Relative Impact = [(treatment/control) – 1] *100. Values in brackets are none transformed

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Table 4: **Effect of *Argemone ochroleuca* on concentrations, germination percentage (GP), germination speed (GS), mean germination time (MGT), plumule length (PL) and radicle length (RL) of maize seeds**

Conc (g/L)	GP	R.I(%) [y]	GS	R.I(%) [y]	MGT	R.I(%) [y]	MDG	R.I(%) [y]	PL (mm)	R.I(%) [y]
0	1.3(92)^{a}	-	0.4(12)^{a}	-	0.6(32)^{a}	-	0.1(1.3)^{a}	-	1.459(40.20)^{a}	-
10	1.1(77)^{ab}	-16	0.3(11)^{ab}	-8	0.6(28)^{ab}	-8	0.1(1)^{ab}	-9	1.121(25.02)^{b}	-23
20	1.1(73)^{ab}	-19	0.3(9)^{abc}	-14	0.5(26)^{abc}	-12	0.1(1)^{ab}	-11	1.214(34.00)^{b}	-16
30	0.8(48)^{cd}	-43	0.3(7)^{bcde}	-28	0.4(18)^{bcde}	-29	0.1(0.7)^{bcd}	-29	0.829(19.97)^{cd}	-43
40	0.8(52)^{cd}	-43	0.3(7)^{cdef}	-32	0.4(19)^{cde}	-32	0.1(0.7) ^{cd}	-32	0.752(18.80)^{de}	-48
50	1.0(68)^{bc}	-23	0.3(8)^{bcd}	-21	0.5(24)^{abcd}	-17	0.1(1)^{abc}	-15	1.010(24.88)^{bc}	-31
60	0.7(40)^{d}	-49	0.2(6.)^{cdef}	-31	0.4(15)^{de}	-35	0.1(0.6)^{cd}	-35	0.541(11.33)^{e}	-63
70	0.7(40)^{d}	-49	0.2(4)^{ef}	-45	0.3(12)^{e}	-44	0.1(0.6)^{cd}	-36	0.514(12.73)^{e}	-65
80	0.6(33)^{d}	-56	0.2(4)^{f}	-50	0.3(12)^{e}	-47	0.1(0.4)^{d}	-44	0.542(15.28)^{e}	-63
90	0.7(38)^{d}	-51	0.2(6)^{def}	-42	0.4(14)^{e}	-42	0.1(0.5)^{d}	-40	0.577(13.73)^{e}	-60
100	0.7(43)^{d}	-48	0.2(7)^{def}	-36	0.4(16)^{de}	-37	0.1(0.6)^{cd}	-36	0.734(15.72)^{de}	-50
P value	0.0000		0.0002		0.0002		0.0007		0.0000	0.0000
$LSD_{0.05}$	0.2924		0.076		0.1299		0.0243		0.2414	0.1943
F-value	5.64		4.49		4.49		3.93		13.24	27.91

[x]Column means followed by the same letter are not significantly different at $P \leq 0.05$ according to Fishers least significant difference. [y]Relative Impact = [(treatment/control) – 1] *100. Values in brackets are none transformed

https://doi.org/10.18697/ajfand.108.21455

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Table 5: Effect of *Argemone ochroleuca* plant parts on mean germination percentage (GP), germination speed (GS), mean germination time (MGT), mean daily germination (MDG), plumule length (PL) and stem diameter (SD) of maize

Plant parts	GP	GS	MGT	MDG	PL (mm)	SD (mm)
Shoots	1.69(41.8)[b]	0.21(5.19)[b]	0.36(14.4)[b]	0.07(0.59)[b]	0.57(12.82)[b]	3.30[a]
Roots	1.01(68.1)[a]	0.30(9. 29)[a]	0.51(24.81)[a]	0.10(0. 97)[a]	1.12(29.29)[a]	2.94[b]
P-value	0.00	0.00	0.00	0.00	0.0000	0.0000
$LSD_{0.05}$	0.12	0.03	0.05	0.01	0.1031	0.0758
F-value	28.53	33.71	29.49	22.87	111.01	22.87

[x]Column means followed by the same letter are not significantly different at $P \leq 0.05$ according to Fishers least significant difference. [y]Relative Impact = [(treatment/control) – 1] *100. Values in brackets are none transformed

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Table 6: Interactive effects of Argemone ochroleuca plant parts and concentration on plant height, number of leaves, dry root mass, dry shoot mass and radicle length of maize seedlings

Powder (g)	Plant part															
	Plant height (cm)				Number of leaves				Dry root mass (g)				Dry shoot mass (g)			
	Roots	R.I[y]	shoots	R.I	Roots	R.I	Shoots	R.I	Roots	R.I	Shoots	R.I	Roots	R.I	Shoots	R.I
0	555.03^{abc}	-	507.37^{bcde}	-	0.65(3.43)^{abcd}	-	0.60(3.00)^{e}	-	0.19^{abc}	-	0.21^{a}	-	0.30^{bcdef}	-	0.40^{abcd}	-
2	494.75^{cde}	-11	595.83^{ab}	-17	0.66(3.53)^{abc}	2	0.68(3.77)^{ab}	12	0.13^{cdef}	-29	0.17^{abcdef}	-21	0.30^{cdef}	-1	0.37^{bcd}	-6
4	558.10^{abc}	0.6	561.80^{abc}	11	0.68(3.80)^{a}	5	0.69(3.87)^{a}	14	0.14^{bcdef}	-28	0.19^{abcd}	-12	0.32^{bcdef}	6	0.41^{abc}	3
6	578.04^{abc}	4	537.27^{abcd}	6	0.67(3.67)^{abc}	3	0.68(3.77)^{a}	13	0.12 ^{def}	-36	0.12^{def}	-43	0.34^{bcde}	14	0.30^{bcdef}	-24
8	437.92^{de}	-21	527.10^{abcd}	4	0.64(3.33)^{bcde}	-2	0.67(3.63)^{abc}	10	0.20^{ab}	-7	0.11^{f}	-49	0.25^{ef}	-18	0.34^{bcde}	-16
10	521.53^{abcd}	-6	522.63^{abcd}	3	0.63(3.27)^{cde}	-3	0.68(3.77)^{ab}	13	0.16^{abcdef}	-17	0.11^{f}	-50	0.32^{bcdef}	6	0.35^{bcde}	-11
12	413.42^{e}	-26	614.27^{a}	21	0.61(3.10)^{de}	-5	0.68(3.83)^{a}	14	0.12^{def}	-36	0.19^{abcde}	-13	0.21^{f}	-29	0.50^{a}	26
14	490.58^{cde}	-12	564.10^{abc}	11	0.65(3.52)^{abcd}	1	0.68(3.83)^{a}	14	0.12^{ef}	-37	0.17^{abcdef}	-19	0.29^{def}	-4	0.42^{ab}	5
P-value	0.0159				0.0215				0.0211				0.0278			
$LSD_{0.05}$	48.816				0.0202				0.0333				0.0575			
F-value	2.98				2.80				2.82				2.65			

[x]Column means followed by the same letter are not significantly different at $P \leq 0.05$ according to Fishers least significant difference. [y]Relative Impact = [(treatment/control) – 1] *100.

Values in brackets are none transformed

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