ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-2931 (Print)
ISSN: 2521-293X (Online)
CODEN: MJSAEJ

Malaysian Journal of Sustainable Agriculture (MJSA)

DOI: http://doi.org/10.26480/mjsa.01.2024.09.14

RESEARCH ARTICLE

THE GERMINATION AND GROWTH OF *PHASEOLUS VULGARIS* ARE INHIBITED BY CRUDE EXTRACTS OF *ARGEMONE MEXICANA* LEAVES AND ROOTS

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ARTICLE DETAILS

Article History:

Received 20 December 2023
Revised 15 January 2024
Accepted 13 February 2024
Available online 16 February 2024

ABSTRACT

The invasions of *Argemone mexicana* in sub–Saharan Africa's natural habitats negatively affect biological diversity. We investigated *A. mexicana's* suppressive effects on *Phaseolus vulgaris* seed germination (petri dish experiments) and seedling growth (pot experiments). *Phaseolus vulgaris* seeds and seedlings were treated with different *A. mexicana* leaf (AmL) and root (AmR) crude extract concentrations to study their suppressive effects on the test plant. The results revealed that AmL and AmR crude extract suppressed *P. vulgaris* seed germination and seedling growth, particularly at higher concentrations (70% and 100%). At these concentrations, the seed germination inhibition percentage was twice that at lower concentrations (25% and 50%). The number of seeds that germinated at higher concentrations was lower compared to those that germinated at lower concentrations. Correspondingly, seed germination was delayed at higher concentrations compared to lower ones and controls. Moreover, *P. vulgaris* seedling growth vigour was negatively affected as the growth parameters (fresh biomass, root lengths, stem diameters, and heights) under 75% and 100% concentrations of AmL and AmR were lower. Though this study's findings revealed that *A. mexicana* crude extract reduced *P. vulgaris* germination and growth, further research is required to investigate the allelopathic effects of *A. mexicana* on other plant species.

KEYWORDS

Africa, Allelopathy, Common bean, Growth, Invasive, Petri dish, Experiment, sub–Saharan, plant traits

1. INTRODUCTION

The biological invasions and associated problems have been and are still of great concern worldwide (Moshia and Newete, 2019; Ojija, 2021; Ojija and Manyanza, 2021). Preceding studies indicate that people in developing countries, including sub–Saharan Africa, are most vulnerable to biological invasions of alien plants as they depend on subsistence agriculture and biodiversity for their livelihoods (Ojija et al., 2019a; Witt et al., 2018, 2019; Witt and Luke, 2017). The invasive alien plants (IAPs) are among the major problems threatening biodiversity conservation and food production (Malecore and Van Kleunen, 2019; Ojija et al., 2021; Ojija and Ngimba, 2021). They interfere and compete with native plants, including crops, for different resources such as space, water, nutrients, light, and pollinators (Ojija et al., 2021; Sittaro et al., 2023; Yang et al., 2023).

As a result, they compromise ecological integrity and livelihoods, resulting in biodiversity loss and failure to supply ecosystem services that support human sustainability (Guetling et al., 2023; Marchante et al., 2023; Roldão et al., 2023; Pérez et al., 2022; Deeley and Petrovskaya, 2022; Kovács-Hostyánszki et al., 2022). Apart from having suppressive and competitive abilities against native plants and crops, most IAPs also do not have natural enemies in their new range as they possess anti–herbivorous and anti–microbial properties (Ojija et al., 2019b; Ojija and Ngimba, 2021). Additionally, they have allelopathic effects that suppress seed germination, growth, and/or development of nearby plants (Deeley and Petrovskaya, 2022; Wang et al., 2023). These traits cause some IAPs to dominate invaded ecosystems and/or rangelands while displacing native species (Wang et al., 2023). Most IAPs significantly cause global economic losses (Ahamad, 2022; Iqbal et al., 2021; Kovács-Hostyánszki et al., 2022; Roldão et al., 2023; Yang et al., 2023).

The Mexican poppy (*Argemone mexicana* L., Papaveraceae) is one of the deleterious IAPs that threaten biological diversity and food production across the world (Burhan and Shaukat, 1999; Moshia and Newete, 2019). It is an invasive annual herb that grows up to 1 m high with prickles (Brahmachari et al., 2013; Khan and Bhadauria, 2019; Orozco-Nunnelly et al., 2021). Its leaves are about 5 to 11 cm long and spiny; the flowers, which are yellow and scentless, have a diameter of about 4 to 5 cm; and the seeds are black and spherical Figure 1 (Brahmachari et al., 2013). Furthermore, its obovate capsule, which is spiny, is about 3 cm in length (Brahmachari et al., 2013). Though it is native to tropical America (e.g., Mexico, the United States, the Virgin Islands, India, and Nicaragua), *A. mexicana* has been declared an invasive species in other countries, including Tanzania, Botswana, Côte d'Ivoire, Mauritius, Zimbabwe, Kansas, Cuba, and Syria (Moshia and Newete, 2019; Namkeleja et al., 2013; Salih et al., 2021). It has also been naturalized throughout the world as an agricultural weed (Shaukat et al., 2002).

Argemone mexicana, like many other IAPs, has the capacity to colonize both disturbed and undisturbed settings (Moshia and Newete, 2019). It is also well adapted to a variety of environments, i.e., grasslands and savannas. However, it often tends to infiltrate disturbed ecosystems such as railroads, riverbanks, agricultural lands, construction sites, floodplains, and along road verges or roadsides (Brahmachari et al., 2013).

Quick Response Code	Access this article online	
	Website: www.mjsa.com.my	**DOI:** 10.26480/mjsa.01.2024.09.14

Cite The Article: Fredrick Ojija, Hezron Timothy Mwakabona, Hadija Matimbwa (2024). The Germination and Growth of *Phaseolus vulgaris* Are Inhibited by Crude Extracts of *Argemone mexicana* Leaves and Roots. *Journal of Sustainable Agricultures, 8(1): 09-14.*

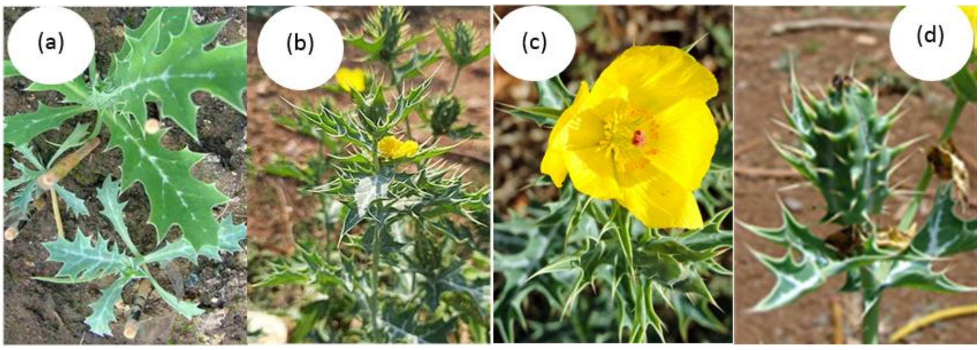
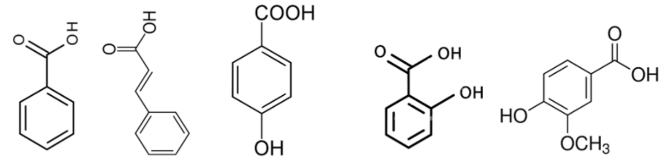


Figure 1: Pictures show the seedlings (a), mature or adult plant (b), flower (c), and fruit of an invasive *Argemone mexicana*. Photos: F. Ojija, 2023

Its invasion is also linked to pastures, arable land, and waste areas, as well as agricultural crops (Moshia and Newete, 2019; Salih et al., 2021). This invasive species frequently outcompetes and displaces native plant species and agricultural crops (Namkeleja et al., 2013). In addition to allelopathic effects, the ability of *A. mexicana* to colonize habitats is attributed by its large seed bank and tolerance to high dryness (Brahmachari et al., 2013; Namkeleja et al., 2013; Shaukat et al., 2002). Additionally, its seeds are easily distributed through a variety of pathways, including contaminated soils, seed products, and crops (Moshia and Newete, 2019; Namkeleja et al., 2014). *Argemone mexicana* produces allelochemicals that can directly or indirectly prevent the growth of nearby native plants or crops that compete with it (Burhan and Shaukat, 1999; Shaukat et al., 2002). This ability is referred to as allelopathy (Salih et al., 2021). The main allelochemicals of *A. mexicana* are phenolic compounds such as benzoic acid, cinnamic acid ((d) (E)-3-Phenylprop-2-Enoic Acid), p-hydroxybenzoic acid (4-Hydroxybenzoic Acid), salicylic acid (2-Hydroxybenzoic Acid), and vanillic acid (4-Hydroxy-3-Methoxybenzoic Acid) (Figure 2).



Benzoic acid   Cinnamic acid   p-hydroxybenzoic acid   Salicylic acid   Vanillic acid

Figure 2: *Argemone Mexicana's* structures of phenolic allelochemicals (Brahmachari et al., 2013; Chen et al., 2002; Namkeleja et al., 2014)

Tanzania has a long history of alien plant species introductions from different geographic regions (Dawson et al., 2008; Mwendwa et al., 2020; Ojija, 2021; Ojija and Manyanza, 2021). Many of the IAPs threaten the country's ecosystem integrity, native biodiversity, economy, and food production (Ngondya and Munishi, 2021). One of the IAPs is *A. mexicana*, which has been increasingly invading natural and semi–natural habitats as well as agroecosystems (Namkeleja et al., 2013). *Argemone mexicana* has been observed invading grasslands and agricultural fields of maize (*Zea mays* L.), common bean (*Phaseolus vulgaris*), and other crops in Tanzania (Namkeleja et al., 2014; 2013). It threatens the country's livestock and wildlife as it is toxic to grazing animals, and most animals, such as cattle, avoid it. Its prickles, which cause nuisance to smallholder farmers and grazing animals, could lead to biodiversity and agricultural loss, as well as a reduction in rangeland and/ or grazing land quality (Brahmachari et al., 2013; Moshia and Newete, 2019). *Argemone mexicana* has also been reported to be a health hazard and suppress seed germination, growth vigour, and the development of plants and crops (Brahmachari et al., 2013; Chen et al., 2002; Salih et al., 2021). In South Africa, *A. mexicana* was declared a noxious IAP because its seeds are harmful to human and animal health when consumed (Brahmachari et al., 2013; Moshia and Newete, 2019; Orozco-Nunnelly et al., 2021). One example of the harmful allelochemicals identified in *A. mexicana* to be responsible for suppression of seed germination and seedling growth vigour are cinnamic and benzoic acids (Barkosky and Einhellig, 2003; Brahmachari et al., 2013; Chen et al., 2002).

Previous studies report that harmful allelopathic effects of *A. mexicana* responsible for suppressing germination and seedling growth of some crops were recorded, for instance, on tomato (*Solanum lycopersicum*), finger millet (*Eleusine coracana*), and cucumber (*Cucumis sativus*) (Barkosky and Einhellig, 2003; Chen et al., 2002; Nxumalo et al., 2022; Salih et al., 2021). Like other IAPs, allelochemicals present in *A. mexicana* may also alter soil properties to favour its growth and invasion. However, based on current knowledge, there has been no study carried out in Tanzania to assess *A. mexicana's* potential suppressive effects on legume crops, notably the common bean (*Phaseolus vulgaris*). Therefore, the study was designed to assess *A. mexicana's* suppressive effects on seed germination and seedling growth of *P. vulgaris*. *Argemone mexicana* leaf (AmL) and root (AmR) crude extracts were used to investigate its suppressive effects on seed germination and seedling growth of *P. vulgaris* using petri dishes and pot experiments, respectively. Different AmL and AmR crude extract concentrations were used to quantify *A. mexicana's* suppressive effect on *P. vulgaris* seed germination and seedling growth. It was hypothesized that AmL and AmR crude extract concentrations will negatively affect (i) seed germination and (ii) seedling stem height, stem diameter, root length, and fresh biomass of *P. vulgaris*. In general, this study is vital and intend to catalyze research on biological invasion to investigate the deleterious effects of IAPs across the world.

2. MATERIALS AND METHODS

2.1 *Argemone mexicana* leaf (AmL) and roots (AmR) crude extract

Several young fresh leaves and roots of *A. mexicana* were collected from invaded areas at Mbeya University of Science and Technology (MUST) (8^{o} 56.24′ S and 33^{o} 25.04′ E, 1636 m a.s.l.) and its surrounding farms (8^{o} 56.45′ S and 33^{o} 25.40′ E, 1643 m a.s.l.) and Iyunga (8^{o} 55.85′ S, 33^{o} 25.05′ E, 1616 m a.s.l.) in the Mbeya region between May and June 2022. This period had suitable weather conditions with little or no rainfall for collecting AmL and AmR samples. Both the leaves and roots were collected in the morning between 6:00 a.m. and 7:30 a.m. to avoid the probable degradation of non–photostable allelochemicals by the sun. Collected AmL and AmR samples were kept in plastic paper bags and transported to the MUST biology laboratory (8^{0} 56.56′ S and 33^{0} 25.21′ E, 1651 m a.s.l.) for processing. They were thoroughly cleaned with water to remove soil and/or debris particles. Afterwards, the AmL and AmR samples were air dried indoors at room temperature to avoid possible degradation of allelochemicals or compounds by ultraviolet (UV) light.

The dried AmL and AmR were separately ground into powder and stored in porous paper envelopes. About 100 g of AmL and AmR powder were measured using a digital balance and soaked in 1 liter of distilled water. The crude was stored in a 4 l plastic container for 48 h in a dark room, and subsequently, the crude extract was filtered using muslin cloth. To get different aqueous concentrations, i.e., 0%, 25%, 50%, 75%, and 100% (w/v) of AmL and AmR (100 ml each), relative to the original extract, the filtrates were diluted with distilled water. The preparation procedures for crude extract concentrations followed those described in (Ojija, 2021; Salih et al., 2021). Germination percentage and inhibition, as well as seedling stem height, stem diameter, root length, and fresh biomass, were used as indicators of *A. mexicana* suppression of early *P. vulgaris* growth (Sensu Nxumalo et al., 2022).

2.2 *Phaseolus vulgaris* seed germination experiment

The *P. vulgaris* seeds were purchased from Ikuti market (S8^{o} 56.07′, E33^{o} 25.18′, 1630 m) in Mbeya Municipal. To investigate the suppressive effect of AmL and AmR crude extracts on *P. vulgaris* seed germination, petri dish experiments were conducted at the MUST biology laboratory (S8^{o} 56.56′, E33^{o} 25.21′, 1651 m). Five glass petri dishes (each with a 70.84 cm^2 surface area) per treatment were used and then replicated five times to make 50 petri dishes, i.e., 25 for each of the AmL and AmR crude extracts. Petri dishes were rinsed with distilled water, dried, and lined with absorbent cotton wool before sowing 15 seeds of *P. vulgaris* in each petri dish. The seeds were irrigated ad libitum (i.e., kept moist) with different concentrations, i.e., 0%, 25%, 50%, 75%, and 100% (w/v) of AmL and AmR. The number of seeds that germinated was recorded daily for 16 days. The 16-day petri dish experiment was within the maximum germination period of common bean seed, which ranges between 7 and 12

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days (Ahmad et al., 2011; Etana and Nebiyu, 2023; Nleya et al., 2005). The criteria used for seed germination during the experiment was the emergence of the radicle (Salih et al., 2021). The seed germination rate and its percentage were calculated and compared between germination periods and concentrations. Also, the germination inhibition percentage (IP) of AmL and AmR crude extract concentrations over the control germination was calculated using the formula below.

$$\text{IP} = \left(\frac{\text{Germinated seeds in extracts} - \text{Germinated seeds in control}}{\text{Germinated seeds in control}}\right)$$

*100 (Ojija et al.,2019b)

2.3 *Phaseolus vulgaris* seedling growth experiment

Seedling growth experiments were conducted in a screen house (8° 56.61′ S and 33° 25.05′ E, 1646 m a.s.l.) at MUST to protect the seedlings from damaging insects such as aphids and white flies. Fifty pots (i.e., twenty–five pots for each AmL and AmR concentration) of 2 l were planted with fifteen (15) *P. vulgaris* seeds each. Pots were watered thoroughly at the time of sowing (i.e., 0.5 l per pot). Following five days of germination, *P. vulgaris* seedlings were irrigated three times per week with AmL and AmR at different crude extract concentrations of 0%, 25%, 50%, 75%, and 100% (w/v). In addition to irrigation, the seedlings were also sprayed ad libitum with AmL and AmR concentrations twice per week using a hand sprayer. The seedlings were treated with AmL and AmR crude extract concentrations for 20 days between June and July 2022. After the experiment, the suppressive effects of AmL and AmR crude extract concentrations on *P. vulgaris* seedling growth were investigated by measuring total fresh biomass, root lengths, stem diameters, and stem heights. Seedlings total fresh biomass was measured using an analytical digital balance; stem diameters were measured using digital callipers above the first two leaves; and heights and root lengths were measured using a meter ruler. In order to ensure that sunlight was spread equally throughout both studies, the locations of the petri dishes and pots were randomized three times per week.

2.4 Statistical data analysis

Comparisons of *P. vulgaris* seed germination and growth parameters (fresh biomass, root lengths, stem diameters, and heights) were compared for different crude extract concentrations of AmL and AmR using a one–way ANOVA and Kruskal–Wallis for parametric and non–parametric data, respectively. Additionally, within a concentration, each growth parameter was compared between treatments (AmL and AmR). Levene's test and Shapiro–Wilk test were used to verify equal variance and normality for all data, respectively. When the parametric assumptions were not confirmed after transformations (using Box-cox and/ or log transformation), the non–parametric Kruskal–Wallis test was used. Significant differences were confirmed using the post hoc Tukey–Kramer HSD and Mann–Whitney pairwise comparison tests. A 0.05 significance level was used for all the tests. Statistical tests were performed with Origin version 9.0 SR1 (2013).

3. RESULTS

3.1 Seed germination under treatments

The results show that both AmL and AmR crude extracts reduced the germination of *P. vulgaris* seed at higher concentrations (Figure 3). Overall, the number of *P. vulgaris* seeds germinated under these concentrations was fewer compared to those germinated at lower concentrations and control (0%) for both AmL (Figure 1a) and AmR (Figure 1b) treatments. Further, both crude extract concentrations delayed *P. vulgaris* seed germination at higher concentrations (75% and 100%) compared to lower concentrations (25% and 50%) and in the control (Figure 3). At higher concentrations, germination started on day 6, while at lower concentrations, especially in the control, it started on day 4 (Figure 3).

The germination of *P. vulgaris* seeds decreased with increasing AmL (Figure 4a) and AmR (Figure 4b) crude extract concentrations. The percentage of seeds germinated at lower concentrations (i.e., 25% and 50%) of AmL crude extract and in the control differed significantly from those germinated at higher concentrations ($F_{(4,20)} = 5.28$, $p = 0.0046$, Figure 4a). The percentage of seed germinated at control 0% (95 ± 2.5) and lower, i.e., 25% (84 ± 4.5) and 50% (80 ± 1.6) AmR concentrations, was high compared to that germinated at higher AmR concentrations, i.e., 75% (68 ± 1.9) and 100% (60 ± 1.8).

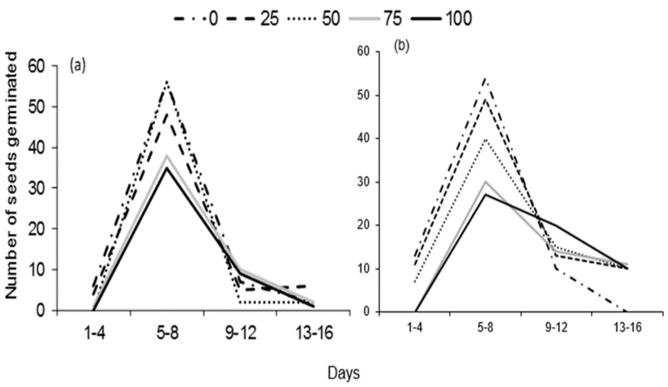

Figure 3: The number of P. vulgaris seeds that germinated under different concentration treatments (i.e., 0%, 25%, 50%, 75%, 100%) of A. mexicana leaf (a) and root (b) crude extracts in petri dishes over the experimental period of 12 days. Both A. mexicana leaf (a) and root crude (b) extracts reduced the germination of P. vulgaris seed at higher concentrations

Furthermore, the percentage of seeds germinated at lower concentrations of AmR crude extract, i.e., differed significantly from those germinated at higher concentrations ($F_{(4,20)} = 8.646$, $p = 0.0003$, Figure 4b). The percentage of seed germinated at control 0% (96.0 ± 2.5) and lower 25% (97 ± 2.7) AmR crude extract concentrations was high compared to that germinated at higher AmR concentrations of 75% (81 ± 0.6, $p = 0.0128$) and 100% (79 ± 1.0, $p = 0.0029$). Under 75% and 100% of AmL and AmR crude extract concentrations, *P. vulgaris* seed germination was suppressed by more than 25% and 35% compared to lower concentrations and control, respectively (Figure 5). Overall, seed germination inhibition increased with increasing AmL and AmR crude extract concentrations (Figure 5).

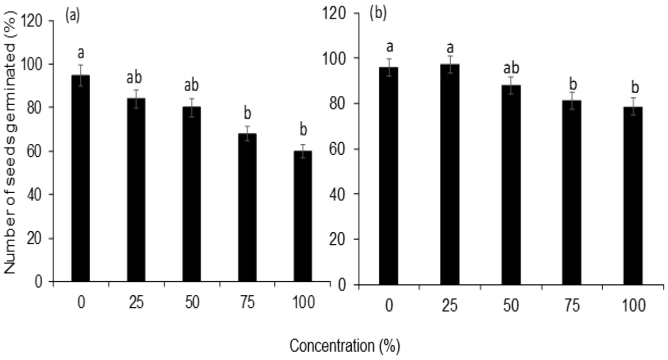

Figure 4: The number of P. vulgaris seeds (Mean ± SE) germinated under different concentrations of Argemone mexicana leaf (a) and root (b) crude extracts over a 16-day experiment in petri dishes. The germination of P. vulgaris seeds decreased with increasing A. mexicana leaf (A) and root (B) crude concentrations. Bars with different letter (s) are significantly different by Tukey-Kramer HSD at p = 0.05

3.2 Seedling growth parameters under treatments

Phaseolus vulgaris seedlings growth vigour was negatively affected as the growth parameters (fresh biomass, root lengths, stem diameters, and heights) under 75% and 100% crude concentrations of AmL and AmR were lower (Table 1). The *P. vulgaris* growth parameters expressed a significant difference between *A. mexicana* treatments and controls. Table 1 shows a significant decrease in growth parameters of *V. vulgaris* as treated with *A. mexicana* crude extract. Stem height (Mean ± SE) of P. vulgaris seedlings treated with *A. mexicana* crude extract differed significantly across different AmL and AmR concentrations (Table 1). The stem height at higher concentrations of AmL (i.e., 100%) was reduced by 9.4 ± 0.11, 6.9 ± 0.06, and 4.8 ± 0.02 compared to lower concentrations, i.e., 0%, 25%, and 50%, respectively. Further, at 75% concentrations of AmL, the mean stem height was reduced by 3.5 ± 0.13 mm, 1.5 ± 0.13 mm, and 6.0 ± 0.05 mm compared to 25%, 50%, and 0%, respectively. Similarly, the mean (± SE) stem height of seedlings treated with 75% and 100% concentrations of AmR was shorter compared to those grown at lower crude extract concentrations and controls. For instance, at 75% AmR crude extract concentration, the stem height was 4.3 ± 0.1 and 2.0 ± 0.1 shorter compared to lower concentrations, i.e., 25% and 50%, respectively (Table 1).

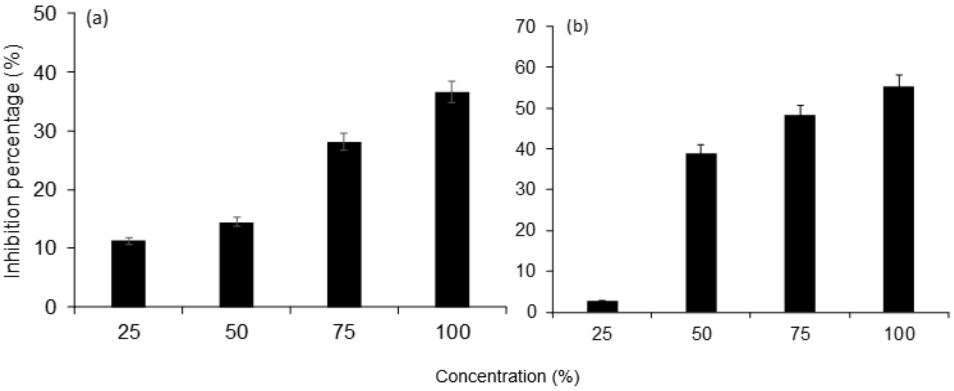

Figure 5: Germination inhibition percentages of *A. mexicana* leaf (a) and root (b) crude extracts at different concentrations over a 16-day experiment in petri dishes. The *P. vulgaris* seed germination inhibition increased with increasing *A. mexicana* leaf (a) and root (b) crude concentrations

Table 1: Growth parameters (Mean ± SE) of *P. vulgaris* seedlings treated with different concentrations of *A. mexicana* leaf (AmL) and root (AmR) crude extract for 20 days in pot experiments.

Growth parameters	*Argemone mexicana* crude extract concentration (%)					Statistical test
	0	25	50	75	100	
AmL treatment						
Stem height (cm)	15.0±0.2^{a}	12.5±0.0^{b}	10.5±0.1^{c}	9.0±0.2^{d}	5.3±0.1^{e}	$H_{(4, 20)}$ = 23.08, p = 0.0001*
Stem diameter (mm)	4.3±0.1^{a}	3.9±0.0^{a}	3.9±0.1^{a}	3.4±03^{b}	2.8±0.2^{b}	$F_{(4,20)}$ =16.95, p < 0.0001*
Root length (cm)	9.2±0.2^{a}	8.8±0.2^{a}	7.3±0.4^{c}	6.4±0.4^{c}	5.9±0.2^{c}	$H_{(4, 20)}$ = 19.85, p = 0.0005*
Fresh biomass (g)	1.6±0.0^{a}	1.5±0.0^{b}	1.5±0.0^{b}	1.4±0.3^{bc}	1.2±0.4^{c}	$F_{(4,20)}$ = 8.86, p = 0.0004*
AmR treatment						
Stem height (cm)	16.2±0.2^{a}	13.4±0.1^{b}	11.1±0.1^{c}	9.1±0.1^{d}	7.4±0.1^{e}	$H_{(4, 20)}$ = 23.08, p = 0.0001*
Stem diameter (mm)	3.9±0.0^{a}	2.7±0.0^{b}	2.6±0.0^{b}	1.5±0.0^{c}	1.3±0.2^{c}	$H_{(4, 20)}$ = 14.71, p = 0.0046*
Root length (cm)	10.2±0.1^{a}	6.0±0.0^{b}	4.1±0.0^{c}	3.4±0.0^{d}	2.5±0.1^{e}	$H_{(4, 20)}$ = 23.08, p = 0.0001*
Fresh biomass (g)	1.4±0.0^{a}	0.7±0.2^{b}	0.7±0.0^{b}	0.6±0.0^{b}	0.3±0.0^{c}	$F_{(4,20)}$ = 26.68, p < 0.0001*

Values with different letter(s) in a row are significantly different by Tukey-Kramer HSD and Mann-Whitney pairwise tests at p = 0.05. * indicates significant difference.

The stem diameter (Mean ± SE) of *P. vulgaris* seedlings differed significantly under both different AmL and AmR crude extract concentrations (Table 1). The diameter of seedlings treated with 75% (AmL: 3.4 ± 03 mm; AmR: 0.5 ± 0.0 mm) and 100% (AmL: 2.8±0.2 mm; AmR: 0.3 ± 0.2 mm) crude concentrations was slightly smaller than those treated with 0%, 25%, and 50% crude extract concentrations (Table 1). Furthermore, the root length (Mean ± SE) of *P. vulgaris* seedlings differed significantly when treated with different crude extract concentrations of AmL and AmR (Table 1). At 75% and 100% concentrations of AmL and AmR, the root length of *P. vulgaris* seedlings was slightly shorter than those treated with 25% and 50% crude extract concentrations and was more than 3.0 ± 0.03 mm shorter compared to the seedlings at 0% (Table 1).

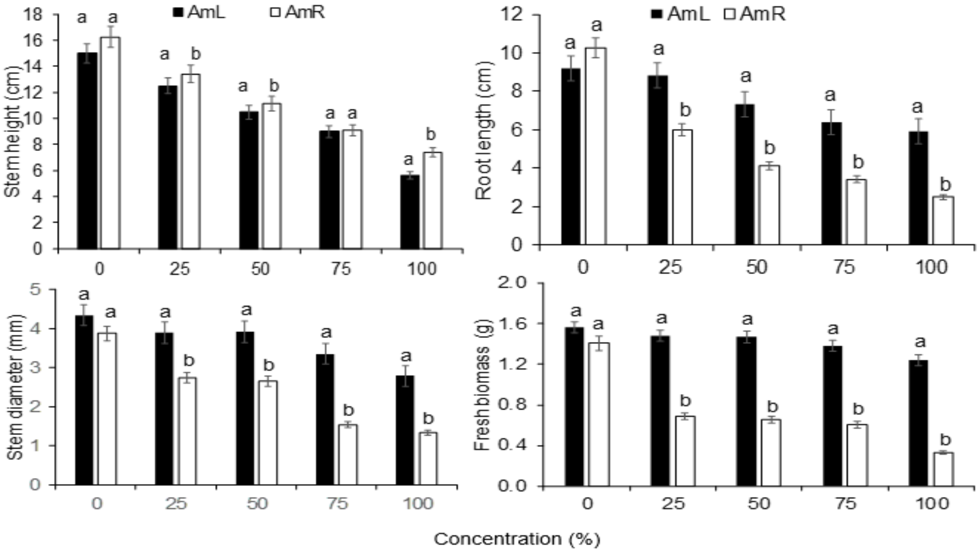

Figure 6: Effectiveness of AmL and AmR crude in suppressing the P. vulgaris seedling growth parameters (Mean ±SE). A comparison was made between AmL and AmR for each crude extract concentration

Moreover, the fresh biomass (Mean ± SE) of P. vulgaris seedlings was reduced at higher concentrations of AmL and AmR (Table 1). The difference between seedling fresh biomass was significant both for AmL and AmR crude extract concentrations (Table 1). For instance, the fresh biomass of seedlings treated with 75% (AmL: 1.4 ± 0.3 g; AmR: 0.6 ± 0.0 g) and 100% (AmL: 1.2 ± 0.4 g; AmR: 0.3 ± 0.0 g) crude concentrations was slightly smaller than those treated with 0%, 25%, and 50% crude extract concentrations (Table 1). In addition, it was found that AmR crude extract concentration was more effective overall in suppressing the growth of P. vulgaris. It strongly suppressed the root length ($p < 0.0001$), stem diameter ($p < 0.0001$), and fresh biomass ($p < 0.0001$) compared to AmL (Figure 6). However, it was observed that AmL crude extract concentrations was effective in suppressing stem height ($p = 0.004$) compared to AmR extract concentration (Figure 6).

4. DISCUSSION

The study highlights that leaf and root crude extracts of an invasive *A. mexicana* have the potential to suppress germination and seedling growth at high concentrations. Studies e.g., that claim that the effectiveness of bio–herbicides is dosage–dependent are supported by the effectiveness of *A. mexicana* crude extract at these high concentrations (Khaliq et al., 2011; Ojija et al., 2019b). *Argemone mexicana* leaf and root crude extract significantly impacted *P. vulgaris* growth by suppressing stem height, stem diameter, root length, and fresh biomass, all of which are indicators of seedling vigour and growth. This finding agrees with previous studies that reported the ability of *A. mexicana* to suppress germination and growth of plants and crops at high crude concentrations (Burhan and Shaukat, 1999; 1999; Paul and Begum, 1970; Salih et al., 2021).

These studies described further that the allelochemicals responsible for suppressing germination and growth of crops are found both in the leaf and roots of *A. mexicana*, which also agrees with the present study. The current results show that high concentrations of AmL and AmR crude extract delayed *P. vulgaris* seed germination. This indicates the presence of allelochemicals in *A. mexicana* which might interfered the physiological processes that trigger *P. vulgaris* germination, and thus, its ability to inhibit seeds germination in the soil. Similarly, *A. mexicana* crude extract demonstrated the ability to weaken *P. vulgaris* seedlings' growth as its growth parameters were more suppressed under high AmL and AmR crude concentration treatments but slightly under low concentrations.

Furthermore, comparing the effectiveness of AmL and AmR crude extract concentrations, it was found that the latter had higher suppressive effects on *P. vulgaris* seedling growth. While AmL crude extract concentrations effectively suppressed stem height, AmR crude extract concentrations strongly suppressed *P. vulgaris* root length, stem diameter, and fresh biomass. This shows that the roots of *A. mexicana* may have had the most allelochemicals (e.g., p-hydroxybenzoic, salicylic, and vanillic acids) responsible for suppressing the growth of other plants (Burhan and Shaukat, 1999; Chen et al., 2002). Also, Paul and Begum made similar observation that the root extract of *A. mexicana* to be more phytotoxic against *Abelmoschus esculentus* germination and seedling growth (Paul and Begum, 1970). However, it should be noted that the effectiveness of allelochemicals present in an invasive plant can be species–specific. This means that some studies may find that the crude extract of *A. mexicana* leaf is the most effective in suppressing a certain plant species, contrary to what the current study has found. For example, according to the findings of Burhan and Shaukat, the effects of phytotoxins from *A. mexicana* appeared to be species–specific, as not all of the studied species were equally suppressed by the extract (Burhan and Shaukat, 1999).

The findings of the current study are further supported by other similar studies that made comparable observations that *A. mexicana* can suppress seed germination and plant growth (Barkosky and Einhellig, 2003, 1993; Namkeleja et al., 2014; Paul and Begum, 1970; Salih et al., 2021). For instance, established that *A. mexicana* aqueous extract negatively affected the germination, stem and root length, and biomass of *Cassia senna* and *Corchorus olitorus* at high concentrations (Salih et al., 2021). Also, asserted that seed germination, shoot and root length, and biomass of *Brachiaria dictyoneura* L and Clitoria *ternatea* L seedlings were suppressed by *A. mexicana* leaf and seed extracts (Namkeleja et al., 2013).

In general, the suppressive activity of *A. mexicana* could be due to active allelochemicals that have been reported in earlier studies (Barkosky and Einhellig, 2003; Brahmachari et al., 2013; Fan et al., 2010; Namkeleja et al., 2013). These allelochemicals include but are not limited to benzoic acid, cinnamic acid, p-hydroxybenzoic acid, salicylic acid, and vanillic acid (Brahmachari et al., 2013; Burhan and Shaukat, 1999; Namkeleja et al., 2013). *Argemone mexicana* uses p-hydroxybenzoic and vanillic acids to interfere with the water balance of nearby plants and suppress their growth (Brahmachari et al., 2013; Chen et al., 2002). As a result, they impact the physiological characteristics of adjacent plants, which cause a decline in the activity of roots, the amount of chlorophyll, and the rate of photosynthesis (Chen et al., 2002). For instance, it was reported that treatment of soybean with high concentrations of p-hydroxybenzoic and vanillic acids decreased its growth and germination (Barkosky and Einhellig, 2003). Further, vanilic acid was also shown to suppress seed germination and seedling growth in eggplant (Chen et al., 2011). Additionally, the ability of *A. mexicana* to suppress seed germination and seedling growth of *P. vulgaris* in this study could be due to salicylic and cinnamic acids (Burhan and Shaukat, 1999). These allelochemicals were previously shown to inhibit seed germination and seedling growth of cowpea, eggplant, and corn and wheat at high concentrations Thus, these allelochemicals that are present in *A. mexicana* can negatively affect the germination, seedling growth, and fresh biomass of *P. vulgaris,* as found in this study (Chen et al., 2011; Burhan and Shaukat, 1999; Barkosky and Einhellig, 1993; Chandra et al., 2007; Namkeleja et al., 2013). But the level of suppressive effectiveness may be species–specific (Burhan and Shaukat, 1999). Overall, *A. mexicana* has the potential to suppress the germination and early–growth of several plants, including crops, as evidenced from the current and previous studies (Moshia and Newete, 2019).

5. CONCLUSION

Since the invasive weed *A. mexicana* exhibits negative effects on other plants in addition to being harmful to humans and livestock, it must be controlled. Nevertheless, it should be noted that the involvement of local communities, especially farmers and pastoralists, must be fully engaged in the management of invasive plants such as *A. mexicana*, because they are directly affected by these invasive weed species. Besides, this study's results showed that *A. mexicana* crude extract reduced *P. vulgaris* germination and growth; nonetheless, field research is required to fully understand the allelopathic effects of *A. mexicana* on other species of plants.

ACKNOWLEDGEMENTS

The authors are greatly acknowledging the valuable in-kind support from Mbeya University of Sciences (MUST) and the Social Health and Environment Management Organization (SHEMO). They are also thankful to Leticia P. Lutambi, Tareq S. Said, Thobias Protaz, Rachel Palangyo, Lusekelo S. Adam, Eclan G. Raphael, and Dorine C. Mkwawa for assisting with the field and laboratory work.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Cite The Article: Fredrick Ojija, Hezron Timothy Mwakabona, Hadija Matimbwa (2024). The Germination and Growth of *Phaseolus vulgaris* Are Inhibited by Crude Extracts of *Argemone mexicana* Leaves and Roots. *Journal of Sustainable Agricultures, 8(1): 09-14.*