Original Research Article

Allelopathic Effects of *Vachellia nubica, Vachellia tortilis* and *Hyphaene compressa* on germination and seedling growth of *Prosopis juliflora*

ABSTRACT

***Background**: Prosopis juliflora* (Sw.) DC is an invasive species negatively impacting plant ecology and livelihoods in introduced areas. Native tree species may produce allelochemicals that can inhibit growth of invasive species, resulting in a natural management technique.

Aim: This study aimed to determine allelopathic effect of three native tree species (*V. tortilis*, *V. nubica,* and *H. compressa)* on seed germination and early seedling growth of *P. juliflora* to identify the tree species that can be used to suppress *P. juliflora* invasion as part of its management strategy.

Methodology: Crude Leaf and root extracts of the native trees at 0%, 1%, 2.5%, 5%, and 10% concentrations were prepared. *P. juliflora* seeds were subjected to 24 crude extract treatments and a control in a completely randomized design in Petri dishes. The seeds were uniformly moistened with 10 ml extracts daily in a germination chamber for 14 days, and germination counts were done after every 2 days. Shoot and root length and wet weight were measured after 14 days. The data were subjected to three-way ANOVA and means separated by Tukey.

***Results:**Prosopis* seed coats treated with *V. tortilis*and *V. nubica* leaf extractsturned darkish before germination while germination of seeds in 10% leaf extracts of *V. nubica* aborted*.* Seed germination percentage in 10% leaf extracts of *V. tortilis (30%)* and *V. nubica (23%)* were the lowest compared to control (90%). *P. juliflora* seedlings under 5% *V. nubica* and 10% *V. tortilis*died before the experiment period*.* Depending on crude extract concentrations, percent inhibition on germination characteristics were; percent germination (21-74%), wet weight (6-49%), plumule length (10-47%), and radicle length (7-86%) of germinating *P. juliflora.*

Conclusion: The native tree species studied have allelopathic effects on the germination of *P. juliflora* and thus can be promoted to suppress invasiveness of *P. juliflora.*

Keywords: Allelopathic effect, Germination, Vachellia tortilis, Vachellia nubica, Hyphaene compressa, Prosopis juliflora

1. INTRODUCTION

Prosopis juliflora (Sw.) DC is an evergreen, small, thorny, fast-growing tree native to South America, Central America, and Caribbean regions [1–4]. The species was introduced to other parts of the world in the late 1970s and early 1980s to combat desertification, deforestation, and fuel wood shortages due to its fast growth and tolerance to drought, waterlogging, highly saline and alkaline soils, provision of a wide range of forest goods and services [2,5–8].

Prosopis juliflora has attracted a lot of attention and contradictory responses in the introduced regions due to unbalanced positive and negative impacts and in most cases negative impacts out loads positive ones. IUCN, (2004) declared the species among the world's least wanted species, that has damaged biodiversity, agricultural systems, human being health and native plant species [9]. *Prosopis juliflora* has threaten ecology of plants and economic well-being of the residents in introduced areas [10–12].The species hascaused negative impacts on soil environment by releasing allelochemicals, dominating landscapes, economic loss, human and animal health and reduced biodiversity. The species compete with native plant species and disrupt ecosystem functions by harming the ecosystem. The species has affected soil properties, land use and land cover changes, hydrology, rangelands, fodder quality and availability, biodiversity reduction, health of humans and livestock, livelihoods of pastoralist, and road accessibility [13]. The severity of the impacts of the species depends on the location of infestation and source of livelihood [14].

The control and management of invasive species such as *P. juliflora* is key in maintaining their negative impacts below ecological and economic thresholds. Biological control effectively controls invasive species since mechanical is labour intensive while chemical control is costly and poses more negative environmental impacts [15]. The common approaches for biological and ecological controls of invasive plants include use of highly resistant native species and manipulating the environmental conditions to weaken the allelopathic effect of invasive species. Allelopathic substances in native tree species can inhibit the growth of alien invasive species, resulting in a natural management technique [16]. Homeland security theory suggests that allelopathic effects may provide a useful tool giving native species an advantage over exotic invasive species helping in restoration [17]. This is an indication that native tree species may have allelopathic effects on the alien invasive species providing an opportunity to reduce the spread, growth, and impacts of the invasive exotic species.

Some native tree species generally are known to produce allelochemicals that may function as a novel weapon against non-native invasive species and thus has the potential to strengthen the resistance of native community to exotic invasion [18]. Native tree species have shown to possess allelopathic effects on exotic invasive species such as *Saccharum spontaneum*[17], *Amaranthus tricolor, Lepidium virginicum, Trifolium repens, Capsella bursa, Crotalaria pallida* [19], *Solidago Canadensis* [20] among others. It is therefore important to explore the allelopathy of native tree species on *P. juliflora* to aid in developing biological control and management techniques. Despite the allelopathic potential of native tree species, there are no attempts to study the allelopathic effects of native tree species on *P. juliflora* to assess possibilities of biological control and management.

This study determined the allelopathic potential of three native species (*Vachellia tortilis* (Forssk.) Galasso &Banfi., *Vachellia nubica* (Benth.) Kyal. &Boatwr., and *Hyphaene compressa* H.Wendl. on the germination of *P. juliflora* as part of efforts to develop biological and ecological control strategies for the management of *P. juliflora* invasive plant in Turkana County, Kenya and other arid and semi-arid lands with similar ecological conditions.Seed germination stage of plants directly affects survival and development of plants [21]. Many allelopathy studies use seed germination tests to detect potential allelopathic effects [22–25].

2. MATERIAL AND METHODS

2.1 Study Sites

The native tree parts (root and leaf) samples for this study were collected from Turkana County located in the Northwest of Kenya. It lies between Latitudes 1° 30'N and 5° 30'N and Longitudes 34° 30'E 36° 40'E. It is classified as Arid and Semi-Arid Land experiencing hot, dry climate with mean temperature and annual rainfall of 30.5 ºC and 200mm respectively. The County has scarce vegetation cover, predominated by *Vachellia* woodlands and *Hyphaene compressa* grows naturally along River Turkwel and Lake Turkana [26,27]. Pastoralism is the main economic activity in Turkana County characterized by rearing of livestock [28].

2.2Selection of StudiedTree Species

Secondary data on the most abundant and dominant native tree species occurring together with *P. juliflora* in Turkana County, Kenya were used to select native tree species for this study. *Vachellia tortilis, Vachellia nubica and Hyphaene compressa* are among the dominant and abundant species in the riverine and non-riverine occurring together with *P. juliflora* in Turkana County [12,29–31]. Their occurrence with the invasive species might be attributed with allelopathic potential leading to resistance of the alien "weapons".

Prosopis juliflora species was selected as a target species because it has negatively impacted the livelihoods of Turkana County, Kenya and other areas where it was introduced and hence a need for its management strategy. Results from this study provides information that can aid in identification of allelopathic native tree species and their allelochemicals that can be used as biocontrol agents in the management of *P. juliflora*.Control of invasive *P. juliflora* in Turkana County and other ASALS areas will contribute to the local and national government targets to manage the species. In *Prosopis* invaded areas, the livelihoods of the residents will improve through reclamation of grazing, farming and fish landing areas that are currently affected severely by the invasive species. Control of the species will also reduce human and livestock health issues in the affected areas.

2.3Collection and Transportation of Samples

Fresh leaves and roots of the selected native tree species were collected from trees randomly sampled, air dried and packed in nylon bags (labeled). Mature *P. juliflora* pods (dry and yellow) were collected from superior quality growing trees that are well formed, healthy and sustain good quality and quantity of seed pods. The pods were opened using scissors to get the seeds for the experiment. The samples were transported to University of Eldoret laboratories for experiments.

2.4Preparation of Crude Leaf and Root Extracts of Different Native Tree Parts

The native tree leaves and roots collected were thoroughly cleaned free of dust and other material, washed with distilled water and air dried. The tree parts were then ground mechanically to fine powder form for extraction to be used for experiments. Crude leaf and roots extracts of the native trees were prepared according to [32]. One hundred gram each of leaf and root powder of different native tree species was dissolved separately in 1 litre of distilled water and gentlyshaken using an orbital shaker for 24 hours. After 24 hours, the solution was filtered using a glass filter, and the resulting filtrate (100g/L) was stored in the refrigerator as stock solutions. The filtrate was then diluted to make 1%, 2.5%, 5% and 10%.

2.5Pretreatment of *P. juliflora* Seeds

The seeds were pre-treated with Concentrated Sulphuric acid according to procedures described by [33]. The seeds were treated with sulfuric acid (30%v/v) for 3 minutes, washed with tap water and dried to break seed dormancy.

2.6Germination Experiment

Twenty-five (25) seeds of *P. juliflora* were spread out in a filter paper placed in the petri dish. There were four replicate Petri dishes for each extract concentration and the native species parts laid out in completely randomized design placed at germination chamber (Temperature-30.5 ^{o}C, Humidy-70%). The seeds in petri dishes were moistened with 5 ml of each extract concentrations and moisture was maintained by adding 5 ml of respective extracts to the petri dishes daily. Distilled water was used as control experiment. Germination count was done at two days' interval after the first germination until there was no further seed germination observed for three consecutive counts. Emergent seedling wet weight, shoot and root length were recorded at the end of the experiment (14 days). Percent germination and percent inhibition were calculated from the measurements as follows:

$$\text{Germination Percentage} = \frac{Number of Germinated Seeds}{Total seeds tested} \times 100$$

Inhibition percentage = $[\frac{C-T}{C}] \times 100$;

where: C – value under the control treatment; T – value obtained under the extract treatment.

2.7Statistical Analysis

Data on effects of leaf and root extracts of native tree species on germination and growth of *P. juliflora* were subjected to Three-way ANOVA using SPSS software Version 20 and Ms Excel. Turkey test was used to separate means at 5% level of significance. The results were presented in form of graphs and tables.

3. RESULTS

3.1 Effect of Leaf and Root extracts of *V. tortilis, V. nubica* and *H. compressa* on Percent Germination of *P. juliflora* Seeds

Prosopis seed coats irrigated with crude extracts of *V. tortilis*and *V. nubica* turned dark before germination while germination of seeds in 10% leaf extracts of *V. nubica* aborted as depicted in Plate 1(a) and Plate (b) respectively.Germinated seeds of *P. juliflora* treated with 5 % *V. nubica,* and 10% *V. tortilis*crude leaf extracts died on day eight (8) and day ten (10) as shown in Plate 1 (c) and Plate 1 (d) respectively. Plate 2 (a) and Plate 2 (b) shows successfully germinated seeds of *P. juliflora* in the control batch and with 1% *V. nubica* crude root extract respectively.

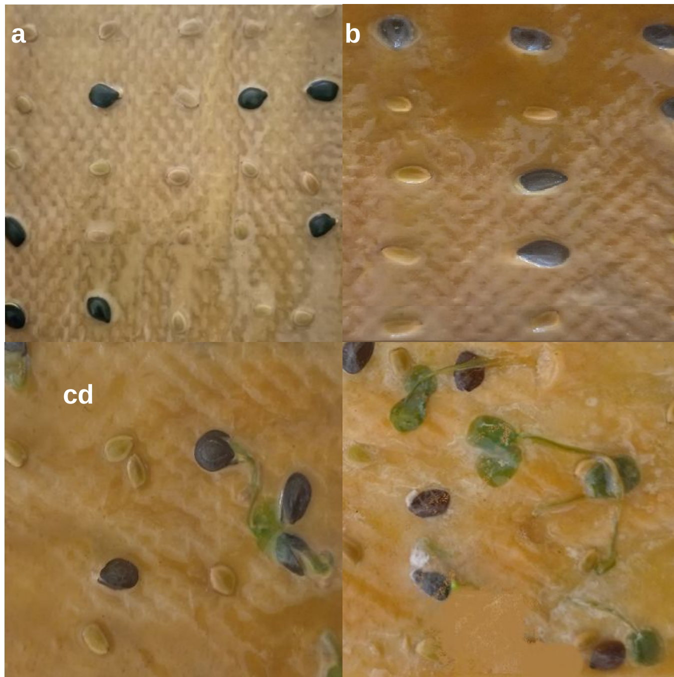

Plate 1: *P. juliflora* seed adversely affected by different crude extracts

Plate 2*: P. juliflora* seeds that were not severely affected

Percent germination of *P. juliflora* seeds was affected by all crude leaf and root extracts of *V. tortilis, V. nubica* and *H. compressa* as compared to the control as shown in Table 1. Germination of *P. juliflora* seeds treated with 10% crude leaf extracts of *V. tortilis*(30%)and *V. nubica* (23%) exhibited the lowest percent germination compared to the control (90%). Percent inhibition of percent germination of *P. juliflora* seeds ranged from 74-21% as shown in Figure 1. An increase in the crude extracts concentrations resulted in increased germination inhibition effects. It was also found that leaf extracts had a greater allelopathic effects on the seed's percent germination than the root extracts. Among the leaf crude extracts *V. nubica* showed a greater (24-75%) inhibition on the germination percentage followed by *V. tortilis* (30-67%) and *H. compressa* (30-61%). Percent germination of *P. juliflora* were significantly different (p=.001; F= 26.98; df=24; n=25) among all the crude extract treatments. The percent germination of all the crude leaf and root extracts of *V. tortilis, V. nubica* and *Hyphaene compressa* was significantly different (p=.001) compared to the control. There was a significant difference in percent germination of *P. juliflora* treated with crude extracts of different tree parts (p=.001; F= 72.99; df=1; n=2) and crude extract concentrations (p=.001; F= 168.023; df=3; n=4). However, Percent germination *P. juliflora* treated with different native tree species were not significantly different (p=.35; F= 1.059; df=2; n=3).

Table 1: Effect of crude leaf and root extracts of *V. tortilis, V. nubica*, and *H. compressa* on percent germination of P. juliflora

Tree species	**Tree Parts**	**Mean Percent Germination at different plant crude extract concentrations (Mean ± SD)**					**Mean (± SD) of Means**	
		Control (0%)	**1%**	**2.5%**	**5%**	**10%**	**Tree Parts**	**Tree Species**
Vachellia tortilis	Leaf	90± 2.3	63± 8.9	52± 6.5	45± 12.8	30± 6.9	**48±11.6**	**51±12.6**
	Roots	90± 2.3	66± 5.2	60± 5.7	52± 5.7	40± 3.3	**54±13.2**	

Vachellia nubica	Leaf	90± 2.3	68± 3.3	51± 5.0	43± 6.8	23± 3.8	**46±17.3**	**52±12.3**
	Roots	90± 2.3	71± 2.0	63± 3.8	55± 2.0	47± 6.0	**59±9.9**	
Hyphaene compressa	Leaf	90± 2.3	63± 6.8	49± 6.0	45± 5.0	35± 5.0	**49±14.8**	**51±13.3**
	Roots	90± 2.3	69± 2.0	63± 3.8	46± 6.9	39± 3.8	**54.±11.0**	
Mean (Concentration)		**90.0**	**66.7**	**56.3**	**47.7**	**35.7**	*p* = .001	*p*= .3500
		p = .001						

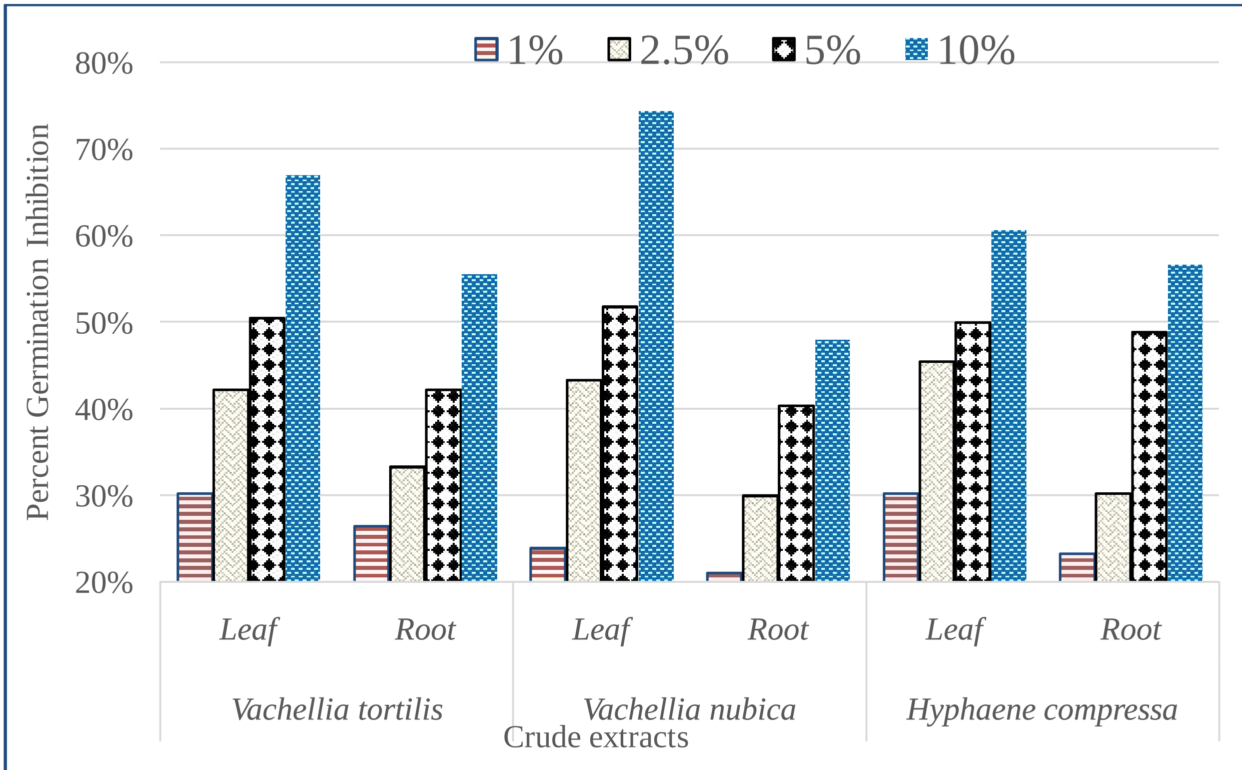

Figure 1: Percent inhibition on *P. juliflora* seed percent germination by crude leaf and root extracts of *V. tortilis, V. nubica*, and *H. compressa*

3.2Effects of Crude Leaf and Root Extracts of *V. tortilis, V. nubica* and *H. compressa* on Plumule Length of Germinating *P. juliflora* seeds

Crude leaf and root extracts of *V. tortilis, V. nubica,* and *H. compressa* reduced the plumule length of *P. juliflora* germinating seed, as shown in Figure 2. The longest plumule length (3.476 cm) was recorded in control germinating seeds, whereas the shortest plumule length (1.833 cm) was noted in germinating seeds treated with 2.5% crude leaf extracts of *V. nubica*. measurements of plumule length of *P. juliflora* emergent seedlings treated with the crude leaf extracts of 10% and 5% *V. nubica* and 10 % *V. tortilis*were not taken since they died before the end of the experimental period. For all the studied native tree species, it was noticeable that crude leaf extracts reduced the plumule length than roots extracts. It was also noted that increase in crude extract concentration resulted in an increased reduction in plumule length.There was a significant difference (*p*=.001; *F*= 5.718; *df*=21; *n*=22) in the plumule length of emergent *P. juliflora* seedlings treated with various crude extracts in this study. All crude leaf and root extracts of the studied native tree species were significantly different (*p*=.001) as compared to the control experiment. There was a significant difference in plumule length of *P. juliflora* emergent seedlings treated with different tree species (*p*=.001; *F*= 6.609; *df*=2; *n*=3), tree parts (*p*=.0008; *F*= 11.254; *df*=1; *n*=2), and crude extract concentrations (*p*=.001; *F*= 21.575; *df*=3; *n*=4).

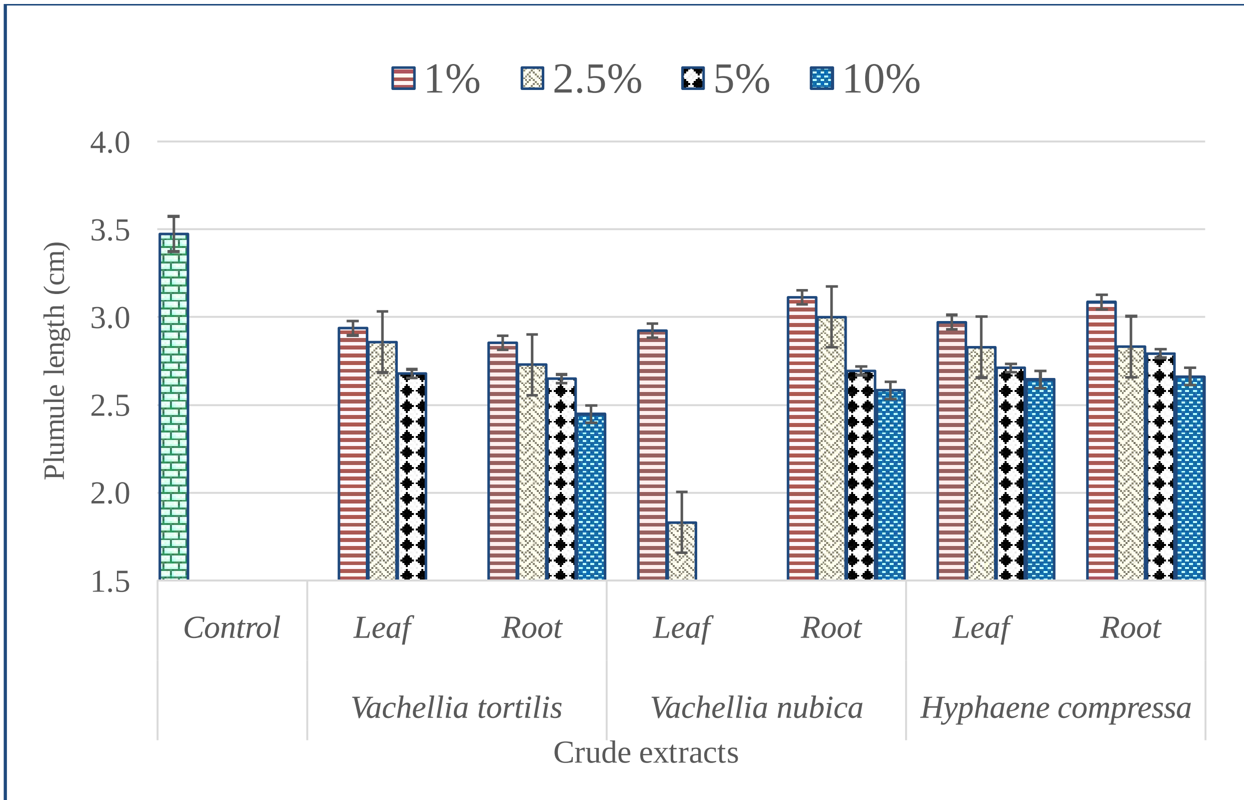

Figure 2: Effect of crude leaf and root extracts of *V. tortilis, V. nubica*, and *H. compressa* on plumule length of *P. juliflora*

Depending on concentration of crude leaf and root extracts, plumule length of the germinating seeding of *P. juliflora* was inhibited by between 10 and 100% as shown in Figure 3. Total inhibition (100%) was noted on seedlings treated with crude leaf extracts of 10% and 5% *V. nubica* and 10 % *V. tortilis,*which died on the 3rd, 9th and 8th day respectively. Among the seedlings that survived until the end of the experimental period, those treated with 2.5% crude leaf extract of *V. nubica* showed the highest percent inhibition at 47%. This study found that an increase in the extract concentration resulted in increased inhibition of plumule length of emergent *P. juliflora* seedlings. It is evident that studied native tree species in this study have potential allelopathic effects on plumule growth of emergent *P. juliflora* seedlings.

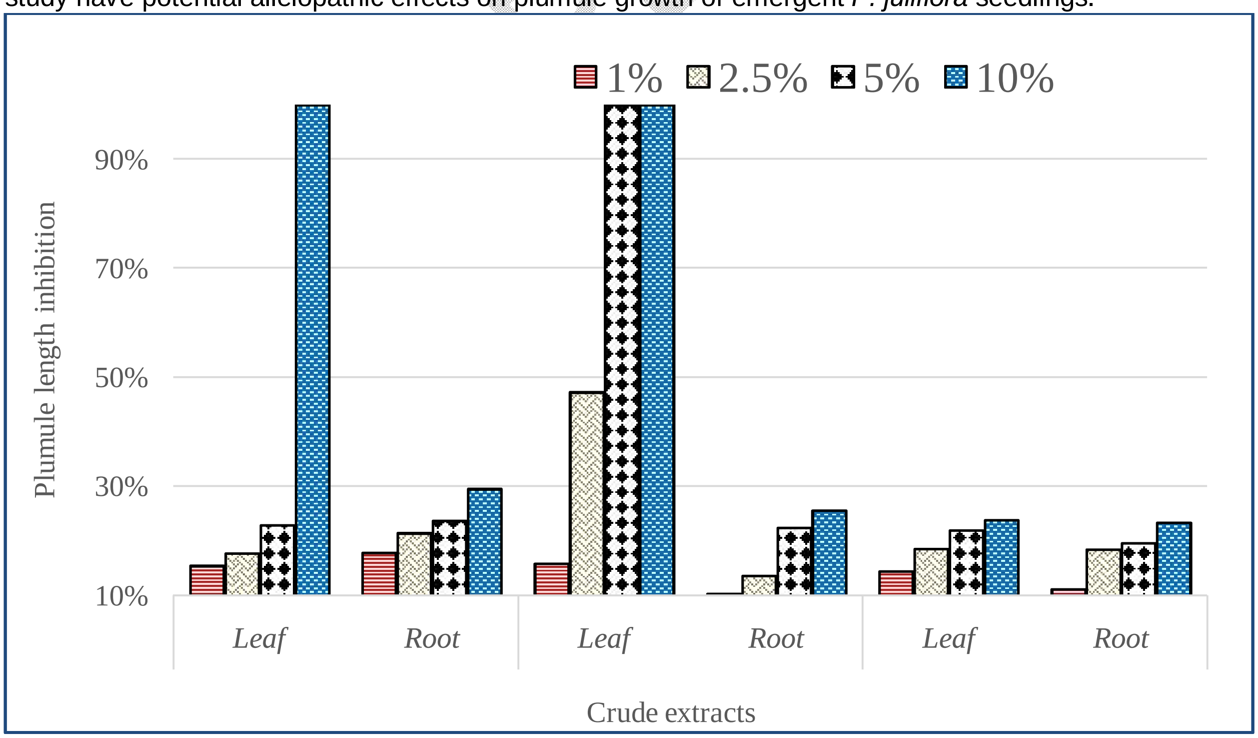

Figure 3: Inhibition of *P. juliflora* seedling plumule length by various crude extracts

3.3 Effects of Crude Leaf and Root Extracts of *V. tortilis, V. nubica* and *H. compressa* on Radicle Length of Germinating *P. juliflora* Seeds

All crude leaf and root extracts of the studied native tree species reduced radicle length of germinating *P. juliflora* seedcompared to control experiment, as shown in Figure 4. Emergent seedlings of *P. juliflora* in control experiment had the longest radicle length (5.06 cm), followed by 1% crude extracts of *H. compressa* leaf (4.71 cm) and root (4.66 cm) and 2.5% crude extracts of *H. compressa* root (4.59 cm) and leaf (4.55 cm). Radicle length of emergent *P. juliflora* seedlings treated with crude leaf extracts of 2.5 % *V. nubica* (0.70 cm), 5 % *V. tortilis* (1.81 cm), 1% *V. nubica* (3.10 cm) and 1% root extract of *V. nubica* (2.79 cm) were highly affected. Radicle length measurements for seedlings under 10 % and 5 % *V. nubica* leaf extracts and 10% *V. tortilis*were not taken because they died before end of experimental period. Radicle length of emergent *P. juliflora* seedlings treated with various concentrations of crude leaf and root extracts of the native tree species extract treatments were significantly different (p=.001; F= 16.457; df=21; n=22). Radicle length of seedlings in all the crude leaf and root extracts had a significant difference (p=.001) compared to control except for crude extracts of *H. compressa* 1% and 2.5% leaf and root and 1% *V. nubica* root. There was also a significant difference in the radicle length of emergent *P. juliflora* seedlings in different native tree species (p=.001; F= 84.089; df=2; n=3), tree parts (p=.001; F= 115.470; df=1; n=2), and crude extracts concentration (p=.001; F= 49.472; df=3; n=4).

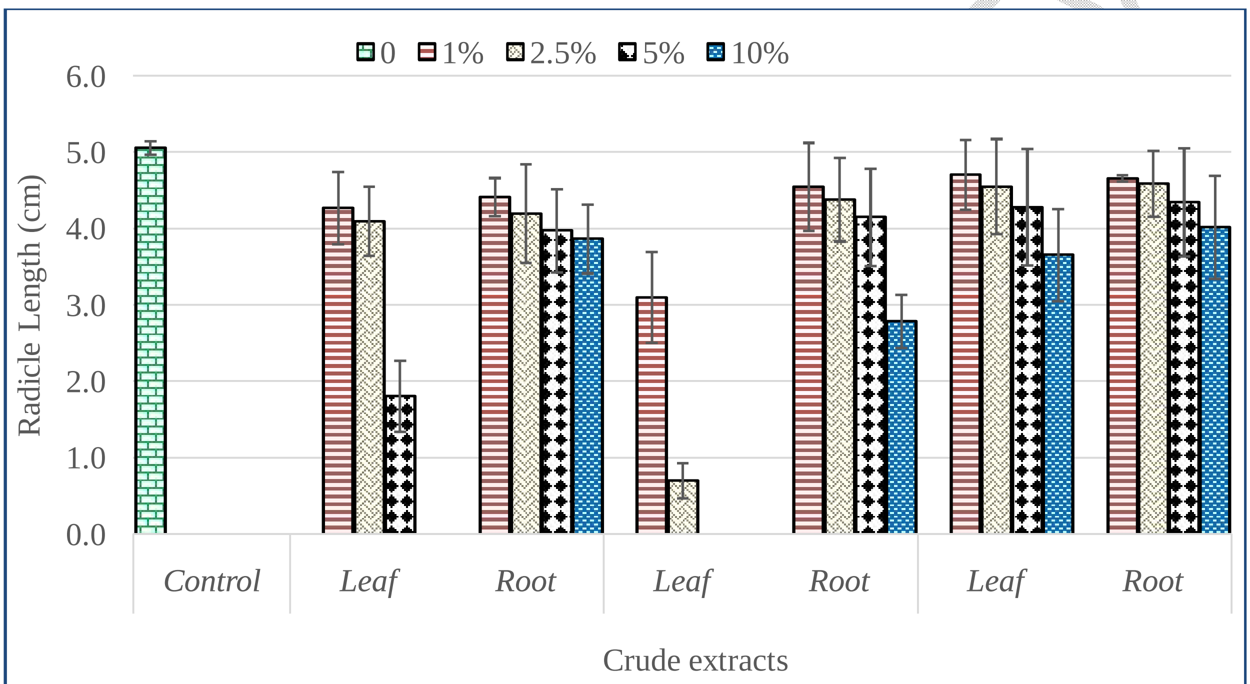

Figure 4: Effect of crude leaf and root extracts of *V. tortilis*, V. nubica, and *H. compressa* on radicle length of P. juliflora

Percent radicle length inhibition of emergent *P. juliflora* seedlings by various crude extracts of *V. tortilis, V. nubica* and *H. compressa* ranged from 7 to 100%, as shown in Figure 5. Crude leaf extracts of 10% and 5% *V. nubica* and 10 % *V. tortilis*depicted 100% radicle length inhibition because the emergent seedlings died before the end of experimental period. Emergent *P. juliflora* seedlings that reached the end of experiment period had their radicle length reduced by 7-86%.The highest radicle length inhibition was recorded in 2.5 % *V. nubica* leaf extracts (87%), *V. tortilis*5% leaf extracts (64%), and *V. nubica* 1 % leaf extracts (39 %). It was found that the percent inhibition was higher in crude leaf extracts than in roots. There was also an increase in the percent inhibition with an increase in the crude extract concentration in all the crude extract treatments.

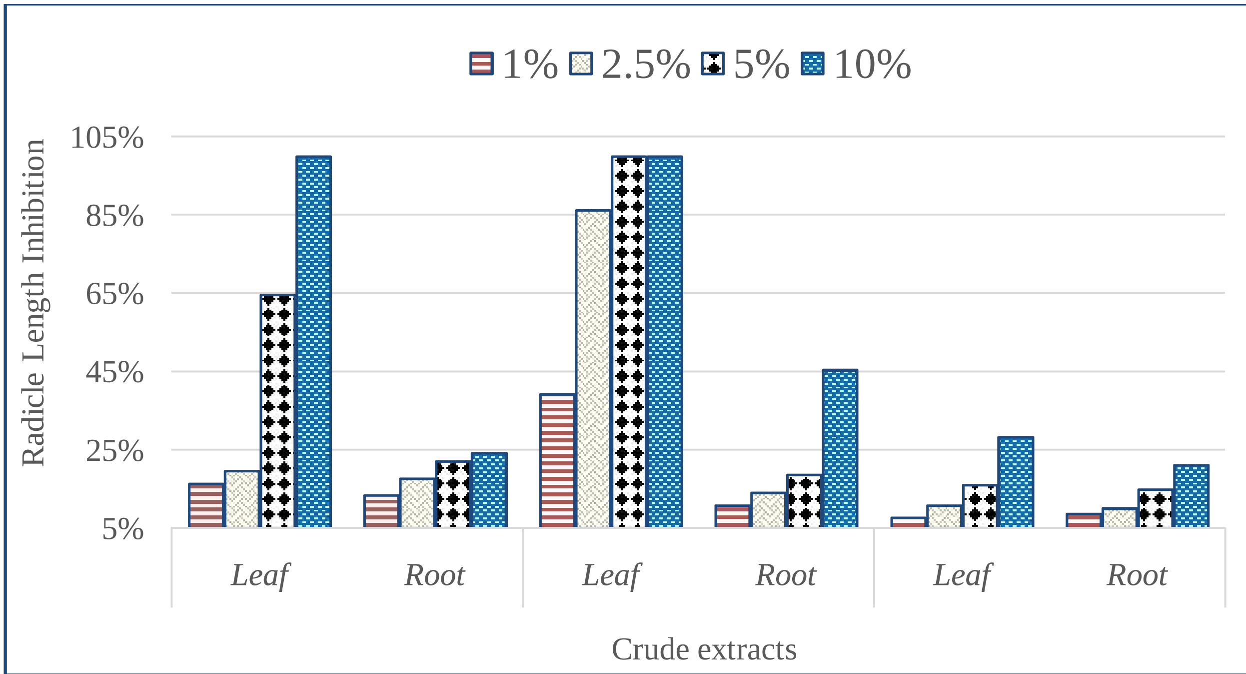

Figure 5: Percent inhibition of *P. juliflora* seedling radicle length by various crude extracts

3.4 Effects of Crude Leaf and Root Extracts of *V. tortilis*, *V. nubica* and *H. compressa* on Wet Weight of Emergent *P. juliflora* Seedlings

Wet weight of emergent *P. juliflora* seedlings was reduced by different crude extracts depending on native tree species, tree parts, and crude extract concentrations, as shown in Table 2. *Prosopis juliflora* emergent seedlings in the control experiment had the highest weight per seedling (0.63 g). For all the studied native tree species, crude leaf extracts (0.32 g) reduced wet weight of emergent *P. juliflora* seedlings than crude root extracts (0.41 g). Among the tree parts, *V. nubica* leaf (0.19 g), *V. tortilis* leaf (0.32 g) and *V. tortilis* root (0.35 g) severely reduced emergent seedling wet weight. *Prosopis juliflora* emergent seedlings in *V. nubica* crude extracts (0.30 g) had the lightest wet weight followed by *V. tortilis* (0.34 g) and lastly *H. compressa* (0.46 g). It was noted that an increase in any crude extract concentration led to the reduction in wet weight of emergent *P. juliflora* seedlings. *Prosopis juliflora* emergent seedlings in various crude extract treatments were significantly different (*p*=.001; *F*= 17.048; *df*=21; *n*=22) in wet weight. Compared to control treatment, all the crude extracts were significantly different (*p*=.001) except 1% crude *H. compressa* crude root extract. There was a significant difference in the seedling wet weight treated with different native tree species (*p*=.001; *F*= 34.765; *df*=2; *n*=3), tree parts (*p*=.002; *F*= 1.085; *df*=1; *n*=2) and crude extract concentrations (*p*=.001; *F*= 47.550; *df*=3; *n*=4).

Table 2: Effect of crude leaf and root extracts of *V. tortilis, V. nubica*, and *H. compressa* on wet weight of *P. juliflora* emergent seedling

Tree species	Tree Parts	Emergent seedling weight (g) at different plant crude extract concentrations (Mean ± SD)					Mean (± SD) of Means	
		Control (0%)	1%	2.5%	5%	10%	Tree Parts	Tree Species
Vachellia tortilis	Leaf	0.63±0.03	0.48±0.01	0.46±0.04	0.34±0.04	0.00±0.00	**0.32±0.07**	**0.34±0.07**
	Roots	0.63±0.03	0.42±0.01	0.35±0.04	0.33±0.02	0.32±0	**0.35±0.05**	
Vachellia nubica	Leaf	0.63±0.03	0.41±0.05	0.33±0.01	0.00±0.00	0.00±0.00	**0.19±0.06**	**0.30±0.06**
	Roots	0.63±0.03	0.47±0.06	0.43±0.03	0.38±0.04	0.36±0.04	**0.41±0.06**	
Hyphaene	Leaf	0.63±0.03	0.57±0.02	0.46±0.07	0.43±0.02	0.33±0.03	**0.45±0.09**	**0.46±0.1**

compressa	Roots	0.63±0.03	0.59±0.12	0.53±0.07	0.4±0.01	0.37±0.01	**0.47±0.11**	
Mean (Concentration)		0.63±0.03	0.49±0.09	0.43±0.08	0.31±0.05	0.23±0.03	*p*= .002	*p*=.001

Crude leaf and root extracts of *V. tortilis*, *V. nubica* and *H. compressa* inhibited wet weight of emergent *P. juliflora* seedlings that survived to the end of experimental period by 6 to 49 % as shown in Figure 6. Therefore, seedlings that died before the end of experimental period exhibited 100% inhibition of wet weight. Percent inhibition increased with increase in the crude extract concentration. Leaf crude extracts had a higher inhibition capacity than root crude extracts.

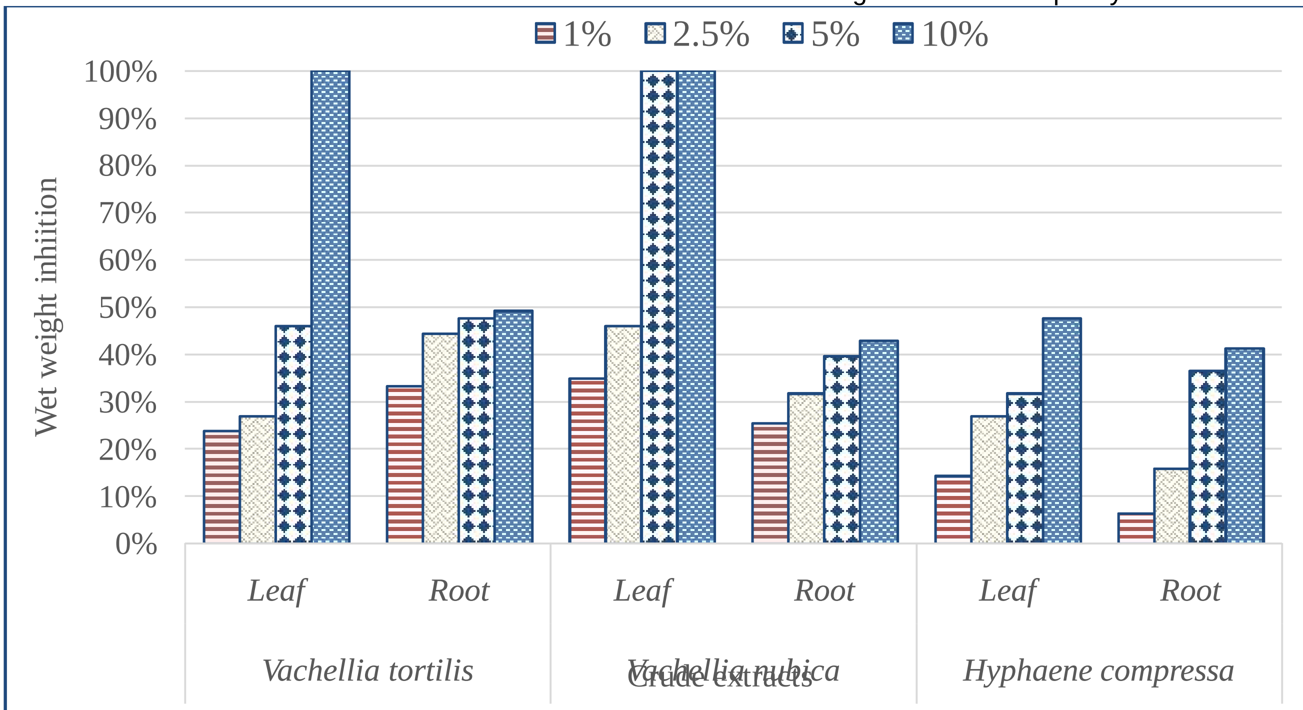

Figure 6: Percent inhibition of *P. juliflora* emergent seedling wet weight

4. DISCUSSION

The crude leaf and root extracts of *V. tortilis, V. nubica* and *H. compressa* native tree species caused *P. juliflora* seed coat scarification exhibited by darkening and acute inhibitory effects on percent germination, shoot and root length, emergent seedling wet weight.Darkened seeds, inhibited percent germination, shoot and radicle length reduction and reduced weight accumulation are among the readily visible allelopathic effects [34,35]. These visible effects might be as a result of primary events occurring at cellular or microcellular levels of *P. juliflora* seeds. This might be because of presence of allelochemicals on the studied native tree species which impair germination characteristics of *P. juliflora*.

Change in seed coat color to dark before germination in *V. tortilis* and *V. nubica* crude leaf extracts might be a response of *P. juliflora* seeds to the crude extracts stress since seed coat plays a protection role against various stress factors. Seeds are highly protective against external stress during germination [36]. Percent germination of *P. juliflora* seeds decreased with increase in crude extract concentration. This shows that the inhibition effects on the percent germination is crude extract concentration dependent [21,23,37,38].

The percent inhibition of the native tree crude extracts on *P. juliflora* seeds varied plant species, parts of plant (i.e leaf or root) and concentration of the extracts. Allelopathic effect is mainly species-specific and concentration-dependent and a strong positive relationship exists between extract concentration and increased toxicity to the target species [39,40]. An increase in crude extract concentration led to increased inhibition effects by crude extras on percent germination, wet weight, plumule and radicle length of germinating *P. juliflora* in the study*.* This is because increase in concentration of the crude extracts increases the quantities of allelochemicals responsible for the inhibition effects [21,41,42]. It is therefore, possible that accumulation of leaf and root litter of the studied native trees in the natural environment can increase concentration of available allelochemicals in the soil, subsequently developing resistance to the invasive *P. juliflora* by allelopathy and this nature of plant to plant interaction may be employed as a natural *P. juliflora* invasion management strategy.

Plumule and radicle length of *P. juliflora* seedlings in this study were reduced with increased crude extract concentration. Percent inhibition by the crude extracts was greater in radicle than plumule length indicating that the radicle is more sensitive to allelopathic effects than the plumule [21,43,44]. Inhibition of plumule and radicle growth indicates inhibition of growth and development of *P. juliflora* because they affect the growth rate at seedling stage and growth of plants respectively [21].

Prosopis juliflora emergent seedling wet weight was also affected by the crude extracts which can be linked to effects of allelochemicals on the metabolism of substance and enzymes functions in the process of seed germination and growthcontrol growth of *P. juliflora*. Seedling wet weight plays a key role in ability of plant to withstand environmental physical stress [38]. By affecting *P. juliflora* seedling wet weight, the studied native tree may affect the invasive species' ability to withstand unfavourable environmental conditions.

Crude leaf extracts of all studied native tree species had a higher inhibitory characteristic than roots in all the germination characteristics. This indicates that the leaves have higher contents of allelochemicals than the roots. [45] reported that leaves are the consistent source of allelochemicals in plants. Among the leaf crude extracts, *V. nubica* tree species showed higher allelopathic effects followed by *V. tortilis* and lastly *H. compressa.*

This study has shown that crude leaf and root extracts of *V. tortilis, V. nubica,* and*H. compressa* have potential allelopathic effects on germination of *P. juliflora.* This indicates potential control of invasive *P. juliflora* by the studied native tree species since germination is a crucial stage in plant growth. Inhibition of the germination stage leads to altered propagation of *P. juliflora*, which affects regeneration, resulting in no further spread of the species.

5. CONCLUSION

This study revealed that crude leaf and root extracts of *V. tortilis, V. nubica,* and*H. compressa* have varying inhibitory effects on percent germination, emergent seedling wet weight, plumule and radicle length of *P. juliflora* seeds. This study shows that the studied native tree species possess potential allelopathic effects on seed germination and seedling growth of *P. juliflora* thus can be promoted to suppress invasiveness of *P. juliflora*.This study recommends study of allelopathic effects of the studied native trees on the growth and field assessment on *P. juliflora.*

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

REFERENCES

1. Abbas AM, Alomran MM, Alharbi NK, Novak SJ. Suppression of seedling survival and recruitment of the invasive tree *Prosopis juliflora* in Saudi Arabia through its own leaf litter: greenhouse and field assessments. Plants. 2023;12(4):959.
2. Kishoin V, Tumwesigye W, Turyasingura B, Wilber W, Chavula P, Gweyi-Onyango Jp, et al. The negative and positive impacts of *Prosopis juliflora* on the Kenyan and Ethiopian ecosystems: A review study. Notulae Scientia Biologicae. 2024;16(1):11832–11832.
3. Orwa C, Mutua A, Kindt R, Jamnadass R, Simons A. Agroforestree Database: a tree reference and selection guide, version 4.0. http://www worldagroforestry org/sites/treedbs/treedatabases asp. 2009;
4. Witt A, Luke Q. Guide to the naturalized and invasive plants of eastern Africa. [Internet]. 2017 [cited 2024 Jul 29]. Available from: https://www.cabidigitallibrary.org/doi/full/10.5555/20173158959
5. Abdulahi MM, Ute JA, Regasa T. *Prosopis juliflora* L: distribution, impacts and available control methods in Ethiopia. Tropical and Subtropical Agroecosystems. 2017;20(1):75–89.
6. de Souza Nascimento CE, da Silva CAD, Leal IR, de Souza Tavares W, Serrão JE, Zanuncio JC, et al. Seed germination and early seedling survival of the invasive species *Prosopis juliflora* (Fabaceae) depend on habitat and seed dispersal mode in the Caatinga dry forest. PeerJ. 2020;8:e9607.

7. Kamiri HW, Choge SK, Becker M. Management Strategies of *Prosopis juliflora* in Eastern Africa: What Works Where? Diversity. 2024;16(4):251.
8. Mwangi E, Swallow B. Invasion of *Prosopis juliflora* and local livelihoods: Case study from the lake Baringo area of Kenya. Nairobi, Kenya: World Agroforestry Centre. 2005;22:1–68.
9. Wittenberg R, Cock MJ. Invasive alien species: a toolkit of best prevention and management practices. Cabi Publishing; 2001.
10. Akall G. Effects of development interventions on pastoral livelihoods in Turkana County, Kenya. Pastoralism. 2021;11(1):23.
11. Akall G. Whose Knowledge Counts?: Irrigation Development in Turkana, Kenya (1963-2019). IGC Proceedings (1997-2023) [Internet]. 2021 Oct 25; Available from: https://uknowledge.uky.edu/igc/24/7/5
12. Nadio CE, Humphrey A, John O. Impacts of *Prosopis juliflora* on Abundance and Species Diversity of Forage Species in Turkana County, Kenya. CJAST. 2020 Nov 5;112–25.
13. Shiferaw W, Demissew S. Effects of the Invasive Alien *Prosopis juliflora* (Sw.) DC and Its Management Options in Ethiopia: A Review. Tropical Plant Species and Technological Interventions for Improvement. 2022;
14. Maundu P, Kibet S, Morimoto Y, Imbumi M, Adeka R. Impact of *Prosopis juliflora* on Kenya's semi-arid and arid ecosystems and local livelihoods. Biodiversity. 2009;10(2–3):33–50.
15. Pasiecznik N. '*Prosopis juliflora* (mesquite)', CABI Compendium. CABI International. 2022;
16. Popovici J, Bertrand C, Jacquemoud D, Bellvert F, Fernandez MP, Comte G, et al. An allelochemical from Myrica gale with strong phytotoxic activity against highly invasive Fallopia x bohemica taxa. Molecules. 2011;16(3):2323–33.
17. Cummings JA, Parker IM, Gilbert GS. Allelopathy: a tool for weed management in forest restoration. Plant Ecology. 2012;213:1975–89.
18. Chen BM, Liao HX, Chen WB, Wei HJ, Peng SL. Role of allelopathy in plant invasion and control of invasive plants. Allelopathy J. 2017;41(2):155–66.
19. Yuan L, Li JM, Yu FH, Oduor AM, van Kleunen M. Allelopathic and competitive interactions between native and alien plants. Biological Invasions. 2021;23(10):3077–90.
20. Adomako MO, Ning L, Tang M, Du DL, van Kleunen M, Yu FH. Diversity-and density-mediated allelopathic effects of resident plant communities on invasion by an exotic plant. Plant and Soil. 2019;440:581–92.
21. Zhao J, Yang Z, Zou J, Li Q. Allelopathic effects of sesame extracts on seed germination of moso bamboo and identification of potential allelochemicals. Scientific Reports. 2022;12(1):6661.
22. Lalbiakdika I, Lalnunmawia F, Lalruatsanga H. Allelopathic effect of common weeds on germination and seedling growth of rice in wetland paddy fields of Mizoram, India. Plant, Soil and Environment. 2022;68(8):393–400.
23. Li J, Chen L, Chen Q, Miao Y, Peng Z, Huang B, et al. Allelopathic effect of Artemisia argyi on the germination and growth of various weeds. Scientific reports. 2021;11(1):4303.
24. Patanè C, Pellegrino A, Cosentino SL, Testa G. Allelopathic effects of Cannabis sativa L. aqueous leaf extracts on seed germination and seedling growth in durum wheat and barley. Agronomy. 2023;13(2):454.
25. Wang C, Liu Z, Wang Z, Pang W, Zhang L, Wen Z, et al. Effects of autotoxicity and allelopathy on seed germination and seedling growth in Medicago truncatula. Frontiers in Plant Science. 2022;13:908426.
26. TCG. Turkana County Integrated Development Plan. CIDP II (2018-2022) [Internet]. 2018. Available from: https://www.cog.go.ke/download s/category/106-county-integrateddevelopment- plans-2018-2022
27. TCG. Turkana County Integrated Development Plan 2023-2027 [Internet]. 2023. Available from: https://turkana.go.ke/download/final-turkana-cidp-iii-2023-2027/
28. Akuja TE, Kandagor J. A review of policies and agricultural productivity in the arid and semi-arid lands (ASALS), Kenya: the case of Turkana County. Journal of Applied Biosciences. 2019;140:14304–15.
29. Akwee PE. Effects Of *Prosopis juliflora* On Plant Abundance And Species Diversity Along Riverine Ecosystem Of River Turkwel In Turkana County, Kenya. International Journal of Innovative Research and Advanced Studies (IJIRAS). 2023;10(8).
30. Akwee PE. Impact Of *Prosopis juliflora* To Biodiversity And Ecosystem Services In Lake Turkana Ecosystem In Turkana County, Kenya. International Journal of Innovative Research and Advanced Studies (IJIRAS). 2023;10(10).
31. Muturi GM, Poorter L, Mohren G, Kigomo BN. Ecological impact of Prosopis species invasion in Turkwel riverine forest, Kenya. Journal of arid environments. 2013;92:89–97.
32. Omer HHM, MOhammed IS. Allelopathic effects of mesquite (Prosopis juliflora) aqueous extracts on seeds germination and seedlings growth of alfalfa, sesame and sorghum. Cell Biology and Development. 2017;1(2):51–4.
33. Asif MJ, Ali A, Mazhar MZ, Tanvir A, Zia B, Anmbreen I, et al. Effect of different pre-treatments on seed germination of *Prosopis juliflora* and Dalbergia sissoo: a step towards mutation breeding. 2020;
34. Mathers HM, Case LT. Natural bioherbicides and related materials and methods [Internet]. US20160165898A1, 2016 [cited 2024 Aug 1]. Available from: https://patents.google.com/patent/US20160165898A1/en
35. Nawab NP, Yogamoorthi A. Allelopathic effects of aqueous extract of Lantana camara L. on seed germination of black gram Vigna mungo L. Environmental Sciences: Indian Journal. 2016;12(11):12.
36. Li W, Khan MA, Yamaguchi S, Kamiya Y. Effects of heavy metals on seed germination and early seedling growth of Arabidopsis thaliana. Plant growth regulation. 2005;46:45–50.

37. Amare T. Allelopathic effect of aqueous extracts of parthenium (Parthenium hysterophorus L.) parts on seed germination and seedling growth of maize (Zea mays L.). Journal of Agriculture and Crops. 2018;4(12):157–63.
38. Laizer HC, Chacha MN, Ndakidemi PA. Allelopathic Effects of Sphaeranthussuaveolens on Seed Germination and Seedling Growth of Phaseolus vulgaris and Oryza sativa. Merah O, editor. Advances in Agriculture. 2021;2021(1):1–9.
39. Kostina-Bednarz M, Płonka J, Barchanska H. Allelopathy as a source of bioherbicides: Challenges and prospects for sustainable agriculture. Reviews in Environmental Science and Bio/Technology. 2023;22(2):471–504.
40. Mersie W, Singh M. Allelopathic effect of parthenium (Parthenium hysterophorus L.) extract and residue on some agronomic crops and weeds. Journal of Chemical Ecology. 1987;13:1739–47.
41. Bibi S, Abu-Dieyeh M, Bibi A, Al-Ghouti M. Allelopathic Effects of the Invasive *Prosopis juliflora* (Sw.) DC. on Native Plants: Perspectives toward Agrosystems. Agronomy. 2023;13(2):59.
42. Raoof KA, Siddiqui MB. Evaluation of allelopathic impact of aqueous extract of root and aerial root of Tinospora cordifolia (Willd.) Miers on some weed plants. An UO Fas Biol. 2012;1:29–34.
43. Turk M, Tawaha A. Allelopathic effect of black mustard (Brassica nigra L.) on germination and growth of wild oat (Avenafatua L.). Crop protection. 2003;22(4):673–7.
44. Wu J, Chen Z, Peng S. Allelopathic potential of invasive weeds: Alternanthera philoxeroide, Ipomoea cairica and Spartina alterniflora. Allelopathy Journal. 2006;17(2):279–86.
45. Scavo A, Restuccia A, Mauromicale G. Allelopathy: principles and basic aspects for agroecosystem control. Sustainable agriculture reviews 28: Ecology for agriculture. 2018;47–101.