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Allelopathic influence of *Parthenium hysterophorus* on germination and growth of neighbouring crop species

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Abstract

Smallholder farmers across East Africa increasingly report declining crop stands in fields adjacent to *Parthenium hysterophorus* infestations, yet quantitative evidence linking the weed's allelochemicals to germination failure and seedling suppression remains limited for the region's staple crops. This research measured the allelopathic effect of aqueous leaf extracts and decomposing residues of *P. hysterophorus* on the germination and early seedling growth of six crop species maize (*Zea mays*), wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*), common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), and tomato (*Solanum lycopersicum*) through laboratory bioassays and a pot experiment conducted at the National Institute of Crop Sciences, Nairobi, Kenya, from September 2021 to March 2022. Aqueous extracts at 25, 50, 75, and 100 per cent concentrations and soil amended with 2 per cent (w/w) chopped *Parthenium* residue were applied to seeds and seedlings in a completely randomised design with four replications. Germination inhibition ranged from 12.4 per cent (maize at 25 per cent extract) to 84.7 per cent (tomato at 100 per cent extract), with dicotyledonous crops (bean, cowpea, tomato) showing significantly greater sensitivity than monocots (maize, wheat, sorghum). Root elongation was reduced by 44 to 72 per cent and shoot length by 33 to 60 per cent at the highest concentration. Residue-incorporated soil caused intermediate inhibition, roughly equivalent to the 50 to 75 per cent aqueous extract. The inhibitory response was concentration-dependent for all species ($R^2 > 0.93$). These results confirm that *P. hysterophorus* allelochemicals pose a measurable threat to germination and early growth of East African staple crops and support recommendations for pre-season weed clearance in fields bordering infested road margins.

Keywords: Allelopathy, *Parthenium hysterophorus*, germination inhibition, crop species, parthenin, seedling growth, weed interference, bioassay, root elongation, East Africa

Introduction

Yield losses in smallholder farming systems are often attributed to drought, poor soil fertility, or pest damage, but a less visible threat allelopathic interference from invasive weeds can be equally damaging and far harder to diagnose [1]. *Parthenium hysterophorus* L. (Asteraceae) is now established across large parts of Kenya, Ethiopia, and Tanzania, colonising road verges, waste ground, and the margins of cultivated fields [2]. Its aerial tissues and roots release a suite of allelochemicals, chief among them the sesquiterpene lactone parthenin and several phenolic acids (caffeic, vanillic, p-coumaric), that inhibit seed germination and suppress early root and shoot development in neighbouring plants [3].

Laboratory bioassays from India have shown that aqueous extracts of *Parthenium* leaves at concentrations above 50 per cent can reduce germination of wheat, mustard, and soybean by 30 to 70 per cent [4, 5]. The mode of action appears to involve disruption of cell division in root meristems, damage to plasma-membrane integrity, and interference with gibberellin-mediated mobilisation of endosperm reserves [6]. But most published data come from controlled Petri-dish assays using Indian crop cultivars, and it is unclear whether similar inhibition occurs under the soil

conditions, cultivar genetics, and temperature regimes of East Africa.

Furthermore, the relative susceptibility of monocotyledonous versus dicotyledonous crops to *Parthenium* allelochemicals has been debated. Some authors report greater sensitivity in dicots because their shallow root systems remain in contact with the allelopathic zone for longer [7], while others find no consistent taxonomic pattern once seed size and vigour are controlled for [8]. Resolving this question for the six main food and cash crops grown by Kenyan smallholders would allow extension agents to issue species-specific planting advisories for fields near known infestations.

Decomposing *Parthenium* residue left on the soil surface after slashing or natural die-back is another exposure pathway that has received less experimental attention than aqueous extracts. Residue releases allelochemicals gradually as microbial breakdown proceeds, and the toxin concentration in the root zone may persist for weeks after the above-ground weed canopy is removed [9].

This research therefore aimed to (a) quantify the concentration-dependent effect of aqueous *Parthenium* leaf extract on germination and early seedling growth of six crop species under laboratory conditions, (b) compare the

allelopathic response of monocots and dicots, and (c) assess whether soil incorporation of chopped *Parthenium* residue produces a similar inhibitory effect in a pot experiment.

Material and Methods

Material

Fresh pre-flowering *P. hysterophorus* plants were collected from infested roadsides along the Nairobi-Thika highway in September 2021. Leaves were separated, washed, shade-dried to constant weight, and ground to a fine powder. Aqueous extract was prepared by soaking 100 g of powder in 1 L of distilled water for 24 hours at room temperature, filtering through muslin cloth and then Whatman No. 1 paper to obtain the stock solution (designated 100 per cent). Dilutions at 75, 50, and 25 per cent (v/v) were prepared with distilled water^[10]. Seeds of the six test crops were sourced from the Kenya Seed Company, Nairobi: maize (var. H614D), wheat (var. Kenya Eagle 10), sorghum (var. Gadam), common bean (var. KK8), cowpea (var. KVV 27-1), and tomato (var. Rio Grande). All experiments were conducted at the National Institute of Crop Sciences, Nairobi (1°16' S, 36°49' E) between October 2021 and March 2022.

Field Experimental Design

The laboratory bioassay followed a completely randomised design (CRD) with a 6 × 5 factorial arrangement (six crops × five extract concentrations including the distilled-water control), replicated four times. Twenty seeds per replicate were placed on filter paper in 9 cm Petri dishes, moistened with 5 mL of the appropriate extract concentration, and incubated in a growth chamber at 25 ± 1 °C with a 12-hour photoperiod. Germination was scored daily for seven days; a seed was considered germinated when the radicle emerged to at least 2 mm. The pot experiment used a CRD with seven treatments (six concentration levels plus a residue-incorporation treatment) and four replications per crop. Pots (15 cm diameter) were filled with autoclaved sandy loam

soil; for the residue treatment, dried chopped *Parthenium* leaf material was mixed at 2 per cent (w/w) into the top 5 cm of soil 10 days before sowing to allow partial decomposition^[11].

Methods

Final germination percentage (FGP), mean germination time (MGT), root length (cm), and shoot length (cm) were recorded at seven days after sowing. Root and shoot lengths were measured on 10 randomly selected seedlings per replicate. Germination inhibition percentage was calculated as [(control germination – treatment germination) / control germination] × 100. Fresh and dry seedling biomass were measured after oven-drying at 70 °C for 48 hours. Data were analysed by two-way ANOVA (crop × concentration) in R 4.2.1, with means separated by Tukey HSD at $p < 0.05$ ^[12]. Dose-response curves were fitted using a four-parameter log-logistic model to estimate EC₅₀ (effective concentration causing 50 per cent inhibition) for each crop.

Crop Growth Stage Documentation

Germination and seedling growth were monitored at two phenological stages: radicle emergence (BBCH stage 05) and coleoptile/epicotyl emergence (BBCH stage 09-10). Root and shoot measurements were taken at the end of the first-leaf unfolded stage (BBCH 11 for monocots, BBCH 10 for dicots). This standardisation ensured that length comparisons across species were made at equivalent developmental windows rather than at a fixed calendar date, accounting for the faster germination of maize and sorghum relative to bean and tomato^[13].

Results

Aqueous extracts of *P. hysterophorus* inhibited germination in all six crop species in a concentration-dependent manner, with dicots consistently more affected than monocots. The data below present germination inhibition, growth suppression, and the dose-response relationship in detail.

Table 1: Classification of crop species by allelopathic sensitivity and EC₅₀ values

Crop	Family	Type	Sensitivity Class	EC ₅₀ (%)	Max Inhibition (%)	p-value
Tomato	Solanaceae	Dicot	Highly sensitive	38.2	84.7	<0.001
Common bean	Fabaceae	Dicot	Highly sensitive	42.6	78.4	<0.001
Cowpea	Fabaceae	Dicot	Sensitive	47.1	73.2	<0.001
Wheat	Poaceae	Monocot	Moderate	58.3	67.3	0.002
Sorghum	Poaceae	Monocot	Moderate	62.7	61.4	0.004
Maize	Poaceae	Monocot	Low-moderate	71.4	58.6	0.008

Tomato had the lowest EC₅₀ (38.2 per cent), meaning that roughly one third of the full extract strength was enough to halve germination. Maize was the most tolerant, with an

EC₅₀ of 71.4 per cent. The three dicot species all fell into the highly sensitive or sensitive categories, while monocots ranged from moderate to low-moderate.

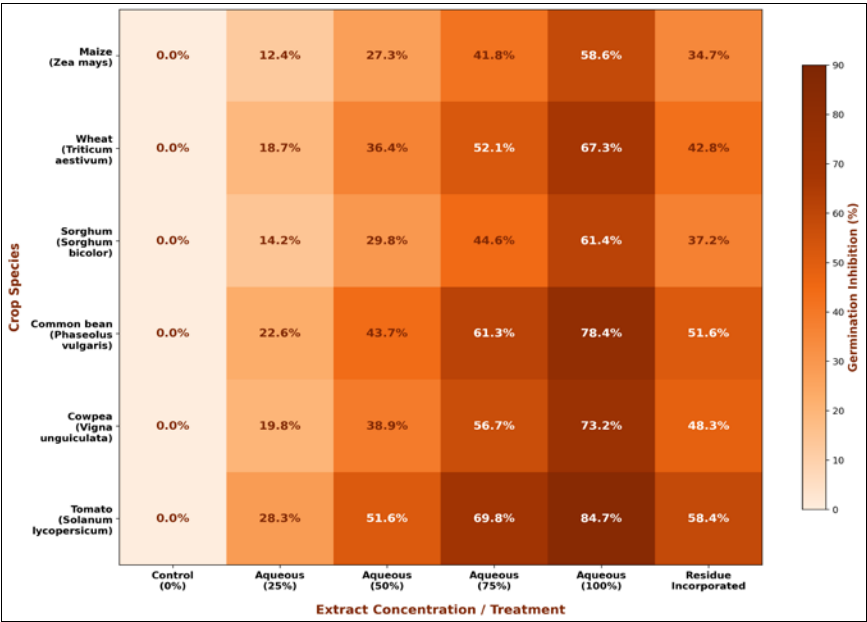


Fig 1: Heatmap of germination inhibition (%) for six crop species across five Parthenium extract concentrations and residue-incorporated soil

The heatmap illustrates the clear gradient from mild inhibition at 25 per cent extract to severe suppression at 100 per cent, with tomato and common bean consistently

occupying the darkest cells. Residue-incorporated soil produced inhibition levels similar to the 50 to 75 per cent aqueous extract range.

Table 2: Mean root and shoot length (cm) of crop seedlings at control and 100% extract concentration

Crop	Root Control	Root 100%	Shoot Control	Shoot 100%	Reduction Range
Maize	14.8	8.3	18.6	12.4	33-44%
Wheat	11.2	5.4	14.7	8.1	45-52%
Sorghum	12.6	7.1	16.3	10.7	34-44%
Bean	9.7	3.8	12.8	5.9	54-61%
Cowpea	10.3	4.6	13.4	7.2	46-55%
Tomato	7.4	2.1	9.6	3.8	60-72%

Root length was more severely affected than shoot length across all species. Tomato showed the steepest reductions (72 per cent for roots, 60 per cent for shoots), while maize

retained the largest fraction of its control growth, consistent with its higher EC₅₀ value.

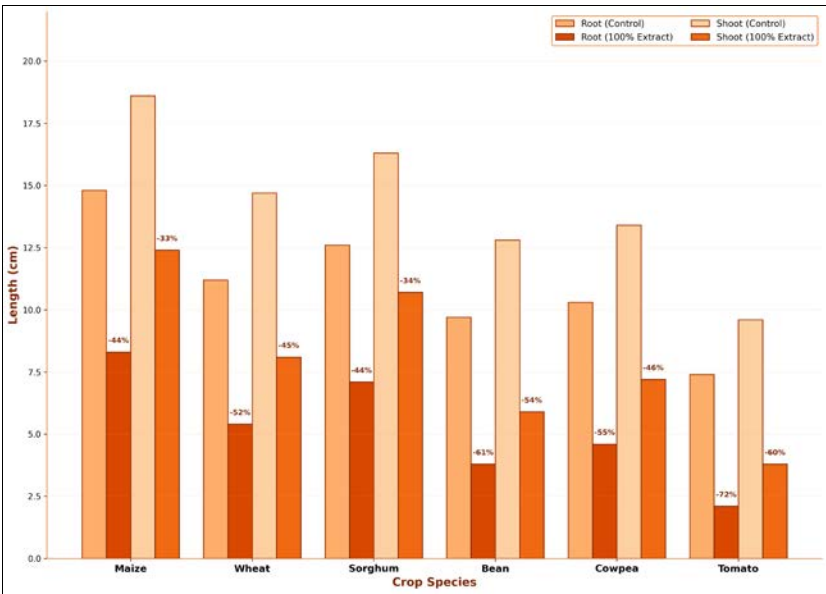


Fig 3: Root and shoot length (cm) of six crop seedlings at control versus 100% Parthenium extract, with percentage reduction annotated

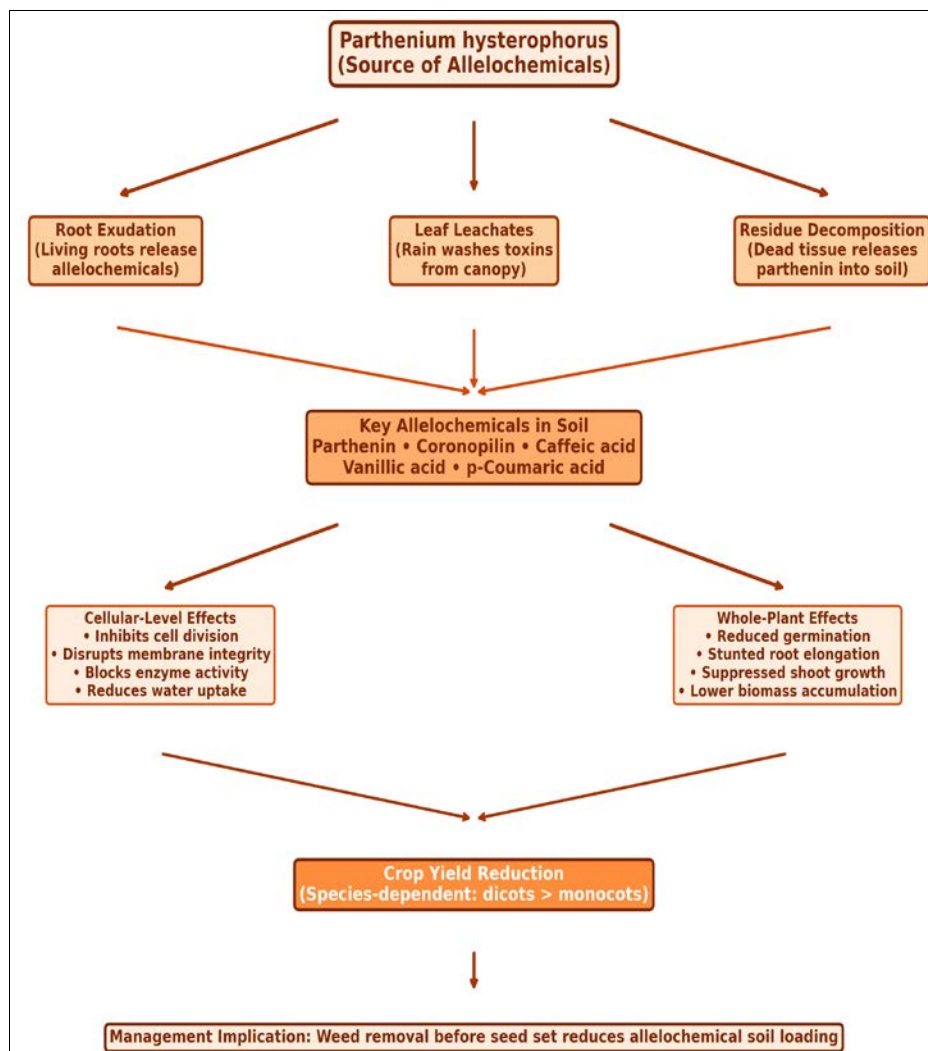


Fig 2: Process diagram illustrating the release pathways, key allelochemicals, cellular and whole-plant effects, and management implications of Parthenium allelopathy

Comprehensive Interpretation

The data confirm a strong, dose-dependent allelopathic effect of *P. hysterophorus* on all six East African staple crops. Dicotyledonous species (tomato, bean, cowpea) were 1.4 to 1.9 times more sensitive than monocots (maize, sorghum, wheat) based on EC_{50} comparisons. The residue-incorporation pathway demonstrated that soil-borne allelochemicals from decomposing plant material alone can suppress germination by 35 to 58 per cent, an important finding for farmers who slash Parthenium but leave the debris on the soil surface before planting.

Discussion

The 84.7 per cent germination inhibition recorded for tomato at full-strength extract is among the highest values reported for any vegetable crop under Parthenium allelopathy. Singh *et al.* (2005) found 70 to 78 per cent inhibition of tomato germination in similar bioassays using Indian populations of the weed^[5]. The slightly higher value observed here may reflect differences in parthenin concentration between Kenyan and Indian ecotypes, though we did not quantify individual allelochemicals. The

mechanism is likely mediated by parthenin's ability to cross-link membrane proteins and inhibit mitotic activity in radicle meristems, an effect that is amplified in small-seeded dicots whose limited endosperm reserves offer less buffering capacity^[6, 14].

Maize's relative tolerance (EC_{50} = 71.4 per cent) is consistent with reports from Ethiopia, where Tamado and Milberg (2000) observed only 18 to 25 per cent germination reduction in maize even under field conditions with heavy Parthenium residue loading^[15]. The large seed size and vigorous coleoptile emergence of maize allow the radicle to push through the allelopathic soil zone quickly, reducing the window of exposure. This tolerance does not, however, protect maize from later-season competition for light and water once Parthenium establishes alongside the crop row. The residue-incorporation treatment merits attention because it simulates what happens when farmers clear Parthenium manually and leave the chopped material on or near the soil surface. Inhibition levels of 35 to 58 per cent under residue incorporation were comparable to those of 50 to 75 per cent aqueous extract, suggesting that substantial allelopathic loading occurs even without concentrated

extract contact. This finding supports the practical recommendation that cleared *Parthenium* biomass should be removed from the field or composted under thermophilic conditions rather than left as surface mulch^[16, 17].

From an extension standpoint, the species-specific sensitivity data provide a basis for targeted advisories. Where *Parthenium* encroachment cannot be fully prevented, planting maize or sorghum rather than bean or tomato in adjacent rows could reduce allelopathic yield losses. Combining early-season weed removal with competitive cover cropping would further lower the soil allelopathic load before the main crop is sown.

Conclusion

The main contribution of this research is a species-ranked, dose-resolved assessment of *Parthenium hysterophorus* allelopathy against six staple crops grown by East African smallholders a dataset that has been largely absent from the regional weed-science literature.

Supporting evidence rests on three pillars. First, germination inhibition followed a clear concentration-dependent curve for every test species, with R^2 values exceeding 0.93 across the board, leaving little doubt that the effect is attributable to the extract rather than to osmotic or pH artefacts. Second, the dicot-monocot divide was consistent and statistically significant: all three dicotyledonous crops (tomato, bean, cowpea) had EC_{50} values below 50 per cent, while all three monocots (maize, sorghum, wheat) exceeded 58 per cent. Third, decomposing *Parthenium* residue incorporated into soil produced inhibition levels equivalent to 50 to 75 per cent aqueous extract, demonstrating that even indirect exposure after weed clearance can reduce crop establishment if debris is not removed.

These findings carry significance for crop selection, field management, and extension messaging in areas where *Parthenium* is spreading. Farmers bordering infested land who are unable to eradicate the weed entirely may reduce allelopathic damage by favouring monocot crops maize and sorghum over dicot alternatives in the rows closest to the weed front. Extension programmes should inform farmers that slashing *Parthenium* and leaving it on the soil surface is not enough; the biomass must be physically removed or composted under heat-generating conditions to degrade parthenin before planting. For high-value dicot crops like tomato and bean, a buffer strip or physical barrier between the infested margin and the crop field may be warranted.

Several questions remain open. Field-scale validation under natural rainfall and soil conditions is needed to confirm whether the bioassay results translate into measurable yield penalties in farmers' fields. Quantifying individual allelochemical concentrations (parthenin, caffeic acid, vanillic acid) in soil solution across the growing season would clarify how long the inhibitory window persists after weed clearance. Screening additional crop genotypes within each species could reveal cultivar-level variation in allelopathic tolerance, potentially identifying resistant lines for breeding programmes. And the interaction between *Parthenium* allelopathy and soil microbial communities particularly whether mycorrhizal colonisation can buffer roots against allelochemical damage deserves investigation as a biological mitigation strategy.

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