International Journal of Agricultural Technology 2026 Vol. 22(6):2555-2568
DOI: https://doi.org/10.63369/ijat.2026.22.6.2555-2568
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Allelopathic effect of purple nutsedge (*Cyperus rotundus* L.) extract on germination, growth, and yield of Cucumber

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Davinci, L., Setyowati, N., Nurjanah, U., Widodo, W., Putri, A. H. and Muktamar, Z. (2026). Allelopathic effect of purple nutsedge (*Cyperus rotundus* L.) extract on germination, growth, and yield of cucumber. International Journal of Agricultural Technology 22(6):2555-2568.

Abstract The application of purple nutsedge (*Cyperus rotundus* L.) extract significantly inhibited germination and growth of cucumber (*Cucumis sativus*). Increasing extract concentration from 2.5% to 10% (w/v) increased the number of abnormal seedlings and reduced radicle length, plumule length, radicle dry weight, and plumule dry weight. Linear regression analysis showed strong negative relationships between extract concentration and seedling growth parameters, with determination coefficients ranging from 0.65 to 0.83. The lowest IC_{50} value was observed in radicle length (4.30%), indicating that radicle growth was the most sensitive parameter to allelochemical exposure. In screen-house evaluation, the extract significantly affected plant height, root dry weight, leaf greenness, number of fruits per plant, and marketable fruit weight. Higher extract concentrations consistently reduced cucumber productivity and fruit quality. These results indicate that purple nutsedge exhibits strong allelopathic effects that inhibit seed germination, vegetative development, and fruit yield of cucumber. Therefore, proper management of this weed is important in cucumber cultivation to minimize its negative impacts, while its allelochemicals also have potential as environmentally friendly bioherbicide agents.

Keywords: Bioherbicide, IC_{50}, Seedling vigor, Weed interference, Weed management

Introduction

Weeds remain one of the major biological constraints to crop production because they compete with crops for light, water, mineral nutrients, and growing space. Their effects encompass more than direct competition for resources, as dense weed populations may modify the crop microclimate and interfere with crop establishment and reproductive development. Although synthetic herbicides remain important components of weed management, their intensive and repeated use has contributed to concerns related to environmental contamination, non-target effects, and the evolution of herbicide resistance. These concerns have encouraged the development of complementary approaches based on plant-

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derived compounds and other ecologically based weed-management tactics (Farooq *et al*., 2011; Khamare *et al*., 2022; Shadab *et al*., 2026).

One potential approach is allelopathy (Ain *et al*., 2023; Kostina-Bednarz *et al*., 2023). It describes chemical interactions in which compounds released by plants influence neighboring organisms and may suppress or stimulate germination and growth. Allelochemicals can be released through root exudation, leaching, volatilization, and decomposition of plant residues, and their effects depend on the chemical properties of the compounds, their concentration, the receiving species, and environmental conditions (Cheng and Cheng, 2015; Dora *et al*., 2025; Setyowati *et al*., 2025). These characteristics have positioned allelopathic compounds as promising sources of bioactive molecules for the discovery and development of environmentally compatible weed management agents (Cheng and Cheng, 2015; Palanivel *et al.,* 2021).

Purple nutsedge is a perennial sedge with extensive distribution in tropical and subtropical agricultural lands. Its competitive success is associated with vigorous vegetative reproduction and a chemically diverse secondary-metabolite profile (Peerzada, 2017). A comprehensive phytochemical review documented phenolic compounds, flavonoids, phenylpropanoids, and numerous sesquiterpenoids in Purple nutsedge, while α-cyperone and nootkatone are among the characteristic compounds reported from its rhizomes and tubers (Xue *et al*., 2023). These chemical groups are relevant to allelopathy because phenolic compounds and terpenoid-related metabolites can interfere with membrane function, nutrient acquisition, oxidative balance, photosynthesis, respiration, and cell expansion in susceptible plants (Mushtaq and Fauconnier, 2024).

Experimental evidence supports the phytotoxicity of Purple nutsedge extracts. Aqueous tuber extracts reduced germination and early seedling growth of soybean in a concentration-dependent manner (Darmanti *et al*., 2015), while aqueous extracts from different plant parts reduced germination and root growth of several vegetable crops, and Purple nutsedge competition strongly reduced fruit number and yield in tomato, eggplant, and pepper (Dhima *et al*., 2016). Purple nutsedge extract has also been reported to inhibit germination and seedling growth in cabbage and tomato (de Souza *et al.,* 2019). More recently, laboratory work with cotton confirmed that increasing concentrations of Purple nutsedge rhizome extract increased abnormal germination and inhibited root and shoot development (Kandhro *et al*., 2016). These findings indicate that the phytotoxic response is expressed particularly during early plant establishment. However, a study on the effect of Purple nutsedge extract on cucumber is rarely documented, promising to improve its productivity.

The practical value of an allelopathic extract, however, cannot be assessed only from a germination bioassay. An extract may inhibit seedling establishment

and subsequently influence vegetative growth, photosynthetic status, biomass allocation, fruit formation, and marketable yield. Recent studies on other allelopathic plants have demonstrated that aqueous extracts can affect cucumber growth and productivity, indicating that cucumber can serve as a sensitive test plant for assessing phytotoxic effects beyond the germination stage (Peranginangin *et al*., 2025). Similarly, allelopathic extracts have been evaluated as potential pre-emergence bioherbicides because they can suppress seed germination and early weed development (Sulistiani *et al*., 2020; Khamare *et al*., 2022).

A quantitative measure of phytotoxicity is also useful for comparing the sensitivity of different plant responses. The IC_{50} represents the concentration associated with a 50% inhibitory response and can be used to identify which growth parameter is most sensitive to an extract. In seed bioassays, radicle growth is often particularly responsive because the emerging root is in direct contact with the treatment solution and is essential for water and nutrient acquisition. Recent reviews emphasize that allelochemicals can alter membrane integrity, oxidative signaling, hormone balance, reserve mobilization, and embryonic tissue growth during germination (Wang *et al*., 2025).

Despite the substantial literature on Purple nutsedge, fewer studies have linked a single aqueous extract treatment series to both early cucumber germination responses and subsequent vegetative and yield responses under a controlled screen-house experiment. The present study therefore evaluated the effect of 0, 2.5, 5, 7.5, and 10% (w/v) aqueous extract of Purple nutsedge prepared from leaves, stems, and tubers on cucumber germination, seedling growth, vegetative growth, and fruit yield. The study also estimated IC_{50} values for selected germination and seedling-growth parameters. The specific objectives were to identify concentrations that inhibit cucumber germination and subsequent growth and yield, and to quantify the sensitivity of early-growth parameters using IC_{50} values.

Materials and methods

Study site and experimental design

The study was conducted from August to October 2025 at the Agronomy Laboratory and the screenhouse of the Faculty of Agriculture, University of Bengkulu, Indonesia. Purple nutsedge was collected from Lempuing Village, Bengkulu City. The plant material consisted of leaves, stems, and tubers. Metavi F1 cucumber seeds were used in this study, while Ultisols, cattle manure, urea, phosphorus, potassium, and distilled water were used as supporting materials.

The experiment consisted of two linked stages: a Petri dish germination bioassay and a screenhouse cucumber growth and yield experiment. A single-factor completely randomized design was used, with five extract concentrations: 0, 2.5, 5, 7.5, and 10% (w/v), each replicated five times. Each experimental unit comprised two Petri dishes in the germination stage and two polybags in the screenhouse stage. The germination assay used ten cucumber seeds per Petri dish.

Laboratory experiment

For extract preparation, freshly collected Purple nutsedge material was washed and oven-dried at 50 °C for three days. The dried material was ground into powder. A stock extract was prepared by mixing 100 g of powder with 1,000 mL of distilled water, followed by shaking at 100 rpm for 24 h and filtration through Whatman No. 1 filter paper. The resulting filtrate was treated as a 10% (w/v) stock solution and diluted with distilled water to obtain the experimental concentrations. In the Petri dish assay, each dish received 10 mL of the corresponding extract and was lined with Whatman No. 1 filter paper.

Germination and seedling responses were assessed seven days after sowing. The recorded responses included normal and abnormal seedlings, radicle length, plumule length, radicle dry weight, and plumule dry weight. Abnormal seedlings were identified from visible developmental abnormalities of the radicle and/or plumule. Dry weights were obtained after oven-drying the respective tissues to constant weight. The variables were summarized at the experimental-unit level before statistical analysis.

Screenhouse experiment

For the screenhouse experiment, the growing medium consisted of Ultisols and cattle manure mixed at a 2:1 volume ratio, with 3 kg of medium placed in each 40 cm × 40 cm polybag. Seven-day-old cucumber seedlings obtained from the laboratory assay were transplanted, with three seedlings initially planted per polybag and thinned to one plant at one week after planting. Plants were watered daily, fertilized twice, trained vertically, and maintained using manual and chemical pest and disease management as required. Fruits were first harvested at 38 days after planting and harvested at five-day intervals for a total of five harvests through 65 days after planting.

The parameters evaluated in this study comprised vegetative growth and yield components, including plant length, number of leaves, total leaf area, leaf greenness (SPAD), root and shoot dry weight, fruit length and diameter, mean

fruit weight, fruit number per plant, marketable and non-marketable fruit weight, total fruit weight, and selected relative biomass indices.

Data analysis

Data were subjected to analysis of variance (ANOVA). Laboratory seedling-growth variables were evaluated at the 1% significance level, while screenhouse variables were evaluated at the 5% significance level. Where treatment effects were significant, means were separated using the least significant difference (LSD) procedure at 5%. Linear regression was used to describe concentration-response relationships and to estimate IC_{50} values for abnormal seedlings, radicle length, plumule length, radicle dry weight, and plumule dry weight. The IC_{50} was determined by analyzing the relationship between treatment concentration and percentage inhibition, with the IC_{50} corresponding to the concentration that resulted in 50% inhibition of the measured response.

Results

Germination and early seedling growth

The Petri dish assay showed a clear concentration-related change in cucumber seedling appearance after seven days. The control treatment was normally developed seedlings, whereas extract concentrations of 2.5–10% increased the numbers of abnormal seedlings. At the higher concentrations, radicles and plumules were visibly shorter, and seedlings showed deformation and reduced development (Figure 1).



Figure 1. Appearance of cucumber test plant seedlings at 7 days after sowing under different purple nutsedge extract concentrations

The extract concentration significantly affected radicle and plumule length, and radicle and plumule dry weight at the 1% level. All calculated F-values for variables exceeded the 1% critical F-value of 4.43 (Table 1). The abnormal-seedling response was non-homogeneous in the original analysis and was therefore treated separately from the ANOVA summary.

Table 1. ANOVA summary for cucumber germination and seedling-growth variables in the Petri dish assay

Variable	F-value	Coeff. Variation (%)	Significance (P<0.01)
Radicle length	82.81	24	**
Plumule length	94.15	18	**
Radicle dry weight	35.85	25	**
Plumule dry weight	90.55	15	**

Radicle length declined linearly with increasing extract concentration. The regression equation was $y = -0.94x + 8.6676$ ($R^2 = 0.8347$). The mean radicle length was 9.25 cm in the control and 7.08 cm at 2.5%, with progressively stronger inhibition at higher concentrations (Figure 2). The IC_{50} for radicle length was 4.30%, the lowest value among the early-growth parameters evaluated.

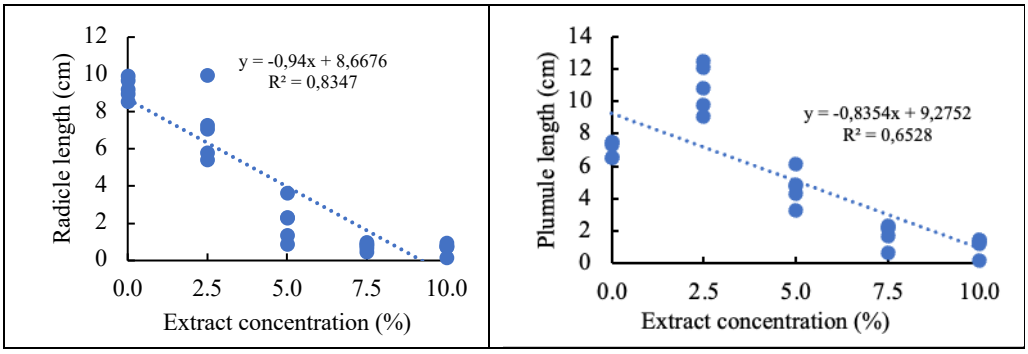


Figure 2. The effect of purple nutsedge extract concentration on radicle and plumule length

Plumule length also showed a negative linear relationship with extract concentration ($y = -0.8354x + 9.2752$; $R^2 = 0.6528$). The response became particularly restricted at 7.5% and 10% extract. The IC_{50} estimate for plumule length was 6.88% (Figure 2). Radicle dry weight followed a negative linear trend ($y = -0.0026x + 0.0286$; $R^2 = 0.8231$), with an IC_{50} of 5.03%. Plumule dry weight similarly decreased with increasing extract concentration ($y = -0.0126x + 0.1452$; $R^2 = 0.8948$), with an IC_{50} of 6.28% (Figure 3).

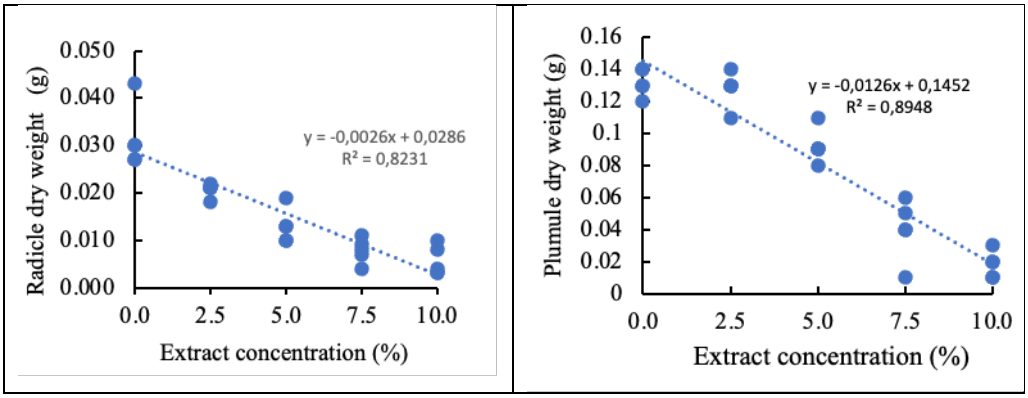


Figure 3. The effect of purple nutsedge extract concentration on radicle and plumule dry weight

Based on the analysis, the IC_{50} values for the evaluated early-growth responses ranged from 4.30% to 6.88%.

Vegetative growth and yield

The screen-house experiment showed that increasing extract concentration generally reduced cucumber vegetative growth. The control plants were visibly more vigorous than plants exposed to the extract, while the 10% treatment showed the shortest plants and fewer leaves and fruits.

ANOVA indicated significant treatment effects on plant length ($F = 3.84$), root dry weight ($F = 3.73$), and leaf greenness ($F = 3.46$) at $p<0.05$. Fruit number per plant ($F = 8.98$) and marketable fruit weight per plant ($F = 8.51$) were significant at $p<0.01$. Leaf number, total leaf area, shoot dry weight, fruit length, fruit diameter, mean fruit weight, non-marketable fruit weight, shoot-to-root ratio, relative shoot length, and relative root-plus-shoot biomass were not significantly affected (Table 3).

Relative to the control, the 10% treatment reduced plant length by 36.1%, root dry weight by 46.4%, total fruit weight by 164.2%, fruit number by 58.33%, and marketable fruit weight by 144.30% (Tables 4 and 5). The numerical reduction was therefore strongest for marketable fruit production, whereas individual fruit length, diameter, and mean fruit weight did not show significant treatment effects.

Table 3. ANOVA summary of cucumber growth, fruit characteristics, and yield variables in the screenhouse experiment

Variable	F-value	Significance
Plant length	3.84	*
Leaf number	1.61	ns
Root dry weight	3.73	*
Shoot dry weight	2.23	ns
Total leaf area	0.71	ns
Leaf greenness (SPAD)	3.46	*
Fruit length	0.58	ns
Fruit diameter	0.93	ns
Fruit number per plant	8.98	**
Mean fruit weight	0.87	ns
Marketable fruit weight	8.51	**
Non-marketable fruit weight	2.00	ns
Shoot-to-root ratio	0.54	ns
Relative shoot length	1.37	ns
Relative root-plus-shoot biomass	0.11	ns

Note: * P<0.05; ** P<0.01; ns = not significant.

Table 4. Effects of purple nutsedge extract concentration on cucumber growth and biomass

Extract (%)	PL[/1] (cm)	LN [/2]	LA[/3] (cm²)	SPAD[/4]	RDW[/5](g)	SDW [/6](g)
0	337.60	34.00	5377	51.44 a[/7]	3.85 a	39.15
2.5	308.90	33.90	6082	51.11 a	3.83 a	34.31
5	297.40	31.70	5808	49.68 ab	3.19 ab	32.35
7.5	276.30	30.80	5101	49.68 ab	3.06 ab	31.00
10	247.90	27.90	4625	48.02 b	2.63 b	26.50

[1/]Plant length [2/]Leaf number [3/]Leaf area [4/]Average Fruit weight [5/]Root dry weight [6/]Shoot dry weight [7/]Means in the same column followed by different letters differ by LSD at 5%.

Table 5. Effects of purple nutsedge extract concentration on cucumber fruit characteristics and yield

Extract (%)	FL[/1] (cm)	FD[/2] (mm)	FW[/3] (g plant⁻¹)	AFW[/4](g fruit⁻¹)	FN[/5] (plant⁻¹)	MFW[/6] (g plant⁻¹)	NFW[/7](g plant⁻¹)
0	22.46	45.78	3944.00 a[8/]	345.30	11.40 a	3342.60 a	23.88
2.5	23.06	45.20	3191.60 ab	345.74	9.20 b	2493.00 b	26.35
5	22.85	46.60	2922.80 bc	366.63	8.00 bc	1927.80 bc	31.22
7.5	22.24	46.28	2625.20 bc	344.83	7.60 bc	1661.40 c	30.77
10	22.27	44.27	2302.40 c	318.97	7.20 c	1368.20 c	30.15

[1/]Fruit length [2/]Fruit diameter [3/] Fruit weight/plant [4/]Average Fruit weight [5/]Fruit number [6/]Marketable fruit weight/plant [7/]non-marketable fruit weight/plant [8/]Means in the same column followed by different letters differ by LSD at 5%.

Discussion

The present study demonstrated that an aqueous extract prepared from leaves, stems, and tubers of Purple nutsedge can inhibit cucumber development from germination through fruit production. The response was expressed most consistently in radicle and plumule growth, seedling dry weight, plant length, root dry weight, leaf greenness, fruit number, and marketable yield. This pattern agrees with the broader literature showing that allelopathic effects can be highly concentration-dependent and may become evident first in sensitive developmental processes such as seed germination and root elongation (Cheng and Cheng, 2015; Wang *et al*., 2025).

The early germination response is particularly important because the radicle is the first organ to emerge and is directly exposed to the aqueous extract. The lowest IC_{50} in the present study was obtained for radicle length (4.30%), indicating that this response was more sensitive than plumule length and the two dry-weight variables. Purple nutsedge contains diverse phenolic and terpenoid compounds, and recent phytochemical reviews have documented a large number of secondary metabolites in the species (Xue *et al*., 2023). Phenolic allelochemicals can interact directly with root cells, alter membrane gradients and nutrient uptake, and disturb oxidative balance, while other allelochemicals can interfere with respiration, photosynthesis, or hormone-regulated growth (Mushtaq and Fauconnier, 2024). These mechanisms may account for the strong response of root elongation before whole-plant effects became evident.

The concentration-response pattern in the present study is consistent with previous Purple nutsedge bioassays. Darmanti *et al*. (2015) reported that increasing concentrations of aqueous tuber extract decreased seedling fresh and dry weight, and seedling length in soybean. Dhima *et al*. (2016) likewise found that aqueous extracts of Purple nutsedge plant parts reduced germination and root length of several vegetable crops. Kandhro *et al*. (2016) reported increasing abnormal germination and inhibition of root and shoot development in cotton as Purple nutsedge rhizome extract concentration increased. The agreement across different recipient species indicates that the inhibitory response is not restricted to a single crop, although the magnitude of response and the threshold concentration vary with donor material, extraction method, recipient genotype, and environmental conditions.

The reduction in seedling dry weight further indicates that the extract affected biomass accumulation rather than only organ elongation. Allelochemicals can interfere with reserve mobilization, respiration, membrane integrity, redox homeostasis, and cell expansion during germination, thereby reducing the supply

of carbon and energy needed for new tissue formation (Wang *et al*., 2025). The relatively high R^2 values obtained for radicle and plumule dry weight (0.82 and 0.89, respectively) indicate strong linear association between concentration and biomass response in the treatment range. The IC_{50} values of 5.03% for radicle dry weight and 6.28% for plumule dry weight place these responses between radicle and plumule length in sensitivity.

The screenhouse results showed that the effect of the extract was not confined to the laboratory stage. Plant length, root dry weight, and leaf greenness were significantly affected, whereas leaf number, total leaf area, and shoot dry weight were not. This combination suggests that cucumber maintained some structural growth traits despite measurable physiological and root effects. The decline in SPAD values from 51.44 in the control to 48.02 at 10% is consistent with the possibility that allelochemical stress altered chlorophyll status or photosynthetic function. Phenolic allelochemicals are reported to influence photosynthetic processes and root nutrient acquisition, although the present study did not directly measure chlorophyll concentration, photosynthetic rate, or nutrient uptake (Mushtaq and Fauconnier, 2024). Therefore, these mechanisms should be regarded as explanatory hypotheses rather than directly demonstrated processes in this experiment.

The differences observed among the yield components indicate that the reduction in overall yield was mainly associated with a decrease in fruit number and marketable production. The reduction in yield was therefore mainly attributable to fewer fruits and reduced marketable production, rather than changes in individual fruit size. At 10% extract, total fruit weight was 164.2% lower than the control, and marketable fruit weight was 144.3% lower. A similar pattern of reduced fruit number and yield has been documented under Purple nutsedge interference with vegetable crops, where both competition and allelopathic activity contributed to yield losses (Dhima *et al*., 2016). The present study isolates the extract treatment from direct weed competition and therefore supports a contribution of chemical interference to the observed yield response.

The response at 5% is also agronomically relevant. At this concentration, total fruit weight, fruit number, and marketable fruit weight were already reduced by approximately 26.95%, 11.11%, and 40.90%, respectively, relative to the control. This study identified 5% as the effective concentration for overall suppression, while the numerical values for several traits continued to decline at 7.5 and 10%. This distinction is important because an effective concentration for a practical bioassay does not necessarily correspond to the concentration producing the absolute minimum of every measured trait. Dose optimization

should therefore consider the target weed, crop selectivity, efficacy, formulation, exposure duration, and economic threshold rather than relying on a single endpoint (Khamare *et al*., 2022).

These findings are also consistent with the broader development of plant-derived bioherbicides. Purple nutsedge tuber-based formulations have been shown to suppress weed germination, supporting the possibility of using nutsedge biomass as a source of pre-emergence bioherbicidal compounds (Sulistiani *et al*., 2020). Reviews of allelopathy emphasize, however, that laboratory phytotoxicity does not automatically translate into field efficacy because allelochemical activity can change with soil properties, microbial degradation, environmental conditions, and formulation (Khamare *et al*., 2022). The present results therefore support further investigation of bioherbicide potential, while additional studies are required to determine field selectivity and environmental safety.

Overall, the combined Petri dish and screenhouse results indicate that aqueous Purple nutsedge extract exhibits measurable phytotoxic activity against cucumber, with radicle elongation identified as the most sensitive indicator of early growth. These results are relevant to the dual role of Purple nutsedge as a competitive weed and a potential source of allelochemicals. Future experiments should test narrower concentrations around the 4.30–6.88% IC_{50} range, characterize the active chemical fractions, examine crop selectivity across additional species, and validate efficacy and persistence under open-field conditions. Such work would be necessary before the extract could be considered as a practical component of integrated weed management.

Acknowledgements

The author gratefully acknowledges the Faculty of Agriculture, University of Bengkulu, for providing the laboratory and screen-house facilities used in this study

Conflicts of interest

The authors declare no conflict of interest.

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(Received: 29 September 2026, Revised: 15 November 2026, Accepted: 17 November 2026)