

# Allelopathic Effects of *Argemone mexicana* to Growth of Native Plant Species

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## Abstract

*Argemone mexicana* is known to have significant effects on cultivated agricultural fields. However, there is little information about allelopathic effect of *A. mexicana* on the growth of wild plant species such as those found in wildlife protected areas. This review presents evidence that allelochemicals present in *A. mexicana* may affect the overall growth of other plant species.

## Keywords

Allelochemicals; Chlorophyll; Ecosystems; Growth

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## 1. Introduction

Invasive alien species are broadly defined as those species that are not native to an area and that may displace or otherwise adversely affect native plant and animal species [1]. Invasive alien species have become a major threat to global biodiversity and this is ranked second position to habitat destruction [2]. The threat posed by invasive species affects natural and managed ecosystem globally with Tanzania not being an exception.

Alien invasive plant species threaten the integrity of agricultural and natural ecosystems throughout the world by displacing native species and establishing mono-species in new habitat [3]-[5]. Competitive ability of invasive species over native species is explained by various hypothesis which includes release from natural enemies that hold them in check and make them free to utilize their full competitive potential [3] [6], evolution of increased competitive ability [7] [8], phenotypic plasticity that helps invasive plants to adapt to novel environments and compete against native plants in recipient communities [9] and the production of allelopathic compounds [3] [4] [10]. Plants can affect neighbouring plants by producing and releasing chemicals into the environment [11]. The Austrian plant physiologist Hans Molish named this phenomenon, “allelopathy” in 1937. Al-

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Allelopathy refers to the effects of one plant on another plant or organisms through the release of chemicals into the environment [4] [12]. These chemicals (allelochemicals) are classified as secondary metabolites and are produced as offshoots of the primary metabolic pathways in plants [13]. Allelopathic effect of some invasive species is stronger on other species in introduced ranges than in native ranges because in new habitat species may not be as adapted to specific allelochemicals of invaders as species do in the native range [10]. Most of invasive plant species has competitive and defensive characteristics which accounts to allelopathic impact [3] [10] [14]. Allelochemicals also affect native species through different pathways that includes interruption of plants nutrients uptake, change in membrane permeability [15], interference in cell division and elongation in roots and shoots [16]-[18], interference in chlorophyll formation [19], protein synthesis inhibition [15] [20] and change or inactivate the activity and functions of certain hormones and enzymes [15] [21].

Allelochemicals from plants are released into the environment by exudation from roots, leaching from stems and leaves or decomposition of plant material [22]. Allelopathic effects can be stimulatory or inhibitory, depending on the identity of the active compound on the static and dynamic availability, persistence and fate of organics in the environment and on the particular target species [23]. Allelopathy has been increasingly recognized as an important ecological mechanism which influences plant dominance, succession, formation of plant communities and climax vegetation and crop productivity [24]. Although *A. mexicana* is allelopathic and invasive alien plant in Tanzania but there is little information about its effect on germination, growth and chlorophyll content of wild plant species used for pasture by livestock and wildlife in agricultural fields and natural ecosystems.

## 2. Allelopathic Potential of *Argemone mexicana*

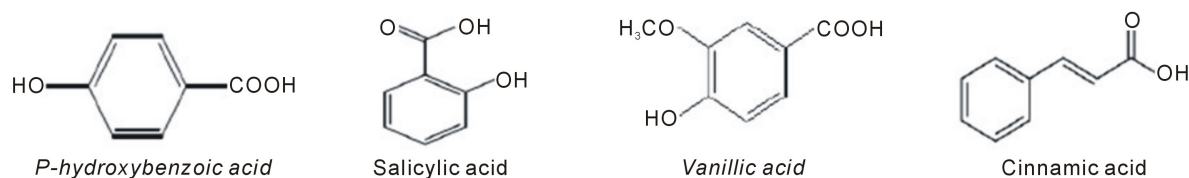
### 2.1. Description of *Argemone mexicana*

*Argemone mexicana* L. a weed native to Central America (Mexico) is one of invasive alien plant species in Tanzania with allelopathic behaviour [25]. *A. mexicana* is a common herb plant found in most places by road sides, agricultural fields and natural ecosystem in Tanzania. *A. mexicana* belonging to the family papaveraceae is a widely distributed plant throughout the tropical and subtropical regions of the world. *A. mexicana* is an annual herb, up to 150 cm tall with a slightly branched tap root [26]. The stem is erect, branched, usually prickly, pale bluish-green and exudes an unpleasant smelling yellow sap when cut. Leaves are alternate, without petioles, more or less sheathing the stem, up to 15 cm long, deeply lobed with irregularly toothed, spiny margins; greyish white veins are conspicuous on the bluish green upper surface of the leaves [27].

It has varying physiology of seed production and germination whereby it can produce seed at an average of 60 to 90 capsules per plant with 300 to 400 seeds in each capsule [28]. Seeds are dormant when shed and after ripening for several weeks or months [29]. Most seeds fall around the base of the parent plant where they form a carpet of seedlings. Most seeds do not normally germinate the year after shedding. Instead they enter the seed bank and seedlings establish, even in well maintained field, probably for many years [25] [29]. Dispersal occurs in surface water and in mud adhering to farm machinery and the feet of man and livestock [30]. Chemical investigations of this plant have revealed the presence of alkaloids, amino acids, phenolics and fatty acids [31]. Therefore some of chemicals in *A. mexicana* might have allelopathic potential that may affect other plants in their vicinity.

### 2.2. Allelochemicals in *Argemone mexicana*

Interaction between plants can be facilitated through release of allelochemicals from donor plants which then influence germination, growth, development, and establishment of receptor plants [16]. These processes play an important role on the determination of vegetation pattern and it is an invasive strategy used by many invasive plant species. In natural ecosystems, allelochemicals produced by invasive plants can inhibit the growth of competing native species through direct or indirect means, thereby providing the invader with a competitive advantage [3] [32] [33]. Phenolic compounds including *p*-hydroxybenzoic acid, vanillic acid and salicylic acid (Figure 1) are the major allelochemicals of *A. mexicana* [34]. Phenolic compounds are amongst the most widespread plant secondary metabolites which are of great significance in plant metabolism like defence against ultraviolet radiation or aggression by pathogens [21]. Phenolic allelochemicals have been observed in both natural and managed ecosystems, where they cause ecological and economic problems, such as decline in crop yield due to soil sickness, regeneration failure of natural forests, and replanting problems in orchards [15].



**Figure 1.** Chemical structures of phenolic allelochemicals found in *Argemone mexicana* [35].

### 2.2.1. 4-Hydroxybenzoic Acid (*p*-Hydroxybenzoic Acid)

*p*-hydroxybenzoic acid is a monohydroxybenzoic acid, a phenolic derivative of benzoic acid. It is slightly soluble in water and chloroform but more soluble in polar organic solvents such as alcohols and acetone. The benzoic acid derivatives produced by higher plants have been frequently implicated in allelopathy [36]. *p*-hydroxybenzoic acid interferes plant-water balance as one mechanism to reduce plant growth. According to Chen *et al.* [19] *p*-hydroxybenzoic acid affects physiological characteristic of plants in their vicinity and hence reduces chlorophyll content, rate of photosynthesis and root activity. Barkosky and Einhellig [37] reported that soybean growth, stomatal conductance and water potential were reduced with application of high concentrations of *p*-hydroxybenzoic acid.

### 2.2.2. 2-Hydroxybenzoic Acid (Salicylic Acid)

Salicylic acid (SA) is a phenolic phytohormone and is found in plants with roles in plant growth and development, photosynthesis, transpiration, ion uptake, transport and induces specific changes in leaf anatomy and chloroplast structure [38] [39]. Salicylic acid plays many roles in plant physiology including pathogenesis related resistance response to abiotic stress [40] by inducing the production of pathogenesis related proteins [41] such as antioxidant enzymes and heat shock protein [42]. It is involved in the Systemic Acquired Resistance (SAR) in which a pathogenic attack on one part of the plant induces resistance in other parts [43]. The signal can also move to nearby plants by salicylic acid being converted to the volatile ester, methyl salicylate. Despite Salicylic acid being one of the important phenolic compound in plants it has also been reported as allelopathic chemical [15]. Effects of salicylic acid on seed germination, seedling growth, and flowering and biochemical activities were studied out in four cowpea (*Vigna unguiculata*) genotypes by Chandra *et al.* [44] and found that both germination and seedling growth were negatively affected. Salicylic acid inhibited growth of soyabean (*Glycine max* L.) seedling and stable carbon isotope ratio (<sup>13</sup>C:<sup>12</sup>C) in tissue of treated plants was higher than control, indicating that salicylic acid caused a water stress [45]. Hence, interference with plant-water relationships is one mechanism whereby this allelochemical inhibits plant growth. In some cases salicylic acid is used as stimulator to decrease adverse effect of allelopathic components of some plant species on germination properties of another species. Saberi *et al.* [46] studied the influence of salicylic acid in decreasing of allelopathic effect of *Eucalyptus camaldulensis* on germination properties of *Onobrychis sativa* and concluded that early seedling growth of *Onobrychis sativa* increased by pre-treatment of seeds in salicylic acid.

### 2.2.3. 4-Hydroxy-3-Methoxybenzoic Acid (Vanillic Acid)

Allelopathic potential of vanillic acid reduced soybean growth, stomatal conductance and water potential [37]. Ghareib *et al.* [47] evaluated allelopathic potential of vanillic acid on tomato and found that at low concentrations of vanillic acid stimulated the germination and growth of tomato and had stimulating effects on the activity of some antioxidant enzymes while at highest concentrations exerted negative effects on all the measured parameters. Inhibition effect on seed germination and seedling growth by vanillic acid on Barnyardgrass (*Echinochloa crus-galli* L) eggplant were also reported by Esmaeili *et al.* [48] and Chen *et al.*, [49]. Since *A. mexicana* contain vanillic acid, there is a possibility of inhibiting germination and growth of some grass and leguminous species growing in natural habitats.

### 2.2.4. (d) (*E*)-3-Phenylprop-2-Enoic Acid (Cinnamic Acid)

Cinnamic Acid (CA) is a widespread phenolic acid released into soil by root exudates, leaf leachates and decomposed plant tissues of different plants such as cucumber [50] and alfalfa [51]. Cinnamic acid is among of phenolic compounds with allelopathic effect that inhibits the germination and growth when applied exogenously

[52]. Cinnamic Acid is an allelochemical responsible for allelopathy in root growth in cucumber [53]; shoot and root length, fresh and dry weight of Cabbage (*Brassica oleracea* var. capitata) seedlings [52]. At high concentration cinnamic acid posed allelopathic effect on verticillium wilt (*V. dahliae*) and eggplant seedling growth [49]. Cinnamic acid is also found in *A. mexicana* and might affect the germination and growth of other plants in their vicinity.

### 2.3. Allelopathic Mechanisms of Phenolics

Allelochemicals changes membrane permeability and inhibit plant nutrient uptake [15]. Cell membrane permeability can be increased by phenolic allelochemicals resulting to spill of cell contents, increased lipid peroxidation and hence slow growth or death of plant tissue [16]. Inhibition of plants from absorbing nutrients from surroundings affects the normal growth of plants. Phenolic allelochemicals may inhibit cell division, elongation, and sub microscopic structure and consequently interferes with the normal growth and development of the whole plant [17] [54]. Disruption of amino acid metabolism is another important mode of action for some allelochemicals [15] [20]. On another hand, phenolic allelochemicals can change the activity and functions of certain enzymes [15]. Some of phenolic allelochemicals reduce or inactivate the physiological activity of plant hormones which may then inhibit the normal physiological process of plants [21]. Hence, the contribution of phenolic compounds to allelopathy is probably not due to a single substance; there are a series of physiological and biochemical changes in plants induced by phenolic compounds. Hence phenolic compounds present in *A. mexicana* may affect germination, seedling growth, fresh weight and chlorophyll contents of target species.

## 3. Effects of Allelochemicals on Seed Germination, Seedling Growth and Chlorophyll Contents

### 3.1. Effects on Seed Germination

Many allelopathic chemicals have more dramatic effects on seed germination than on the growth and viability of matured plants [20]. The allelopathic effects on seed germination are related to the types and concentrations of allelochemicals, species of recipient plants and environmental conditions [55]. Seed germination inhibition by allelochemicals is associated with changes in physiological and biochemical processes necessary for seed germination. Disruption of mitochondrial respiration is one of the mechanisms used by seed to inhibit seed germination [20]. During seed germination, there is a rapid increase in glycolytic activity (Glycolysis) linked to an increased rate of respiration [56]. Glycolytic activity is necessary to mobilize stored carbohydrates to provide the seed with the reducing power, ATP, and carbon products required for the biosynthesis of the roots and aerial parts of the emerging seedling [20]. Therefore, allelochemicals may disrupt activity of metabolic enzymes that are involved in glycolysis [57]. However, all kinds of allelochemicals can affect seed germination through affecting seed cell membrane permeability, cell division and differentiation, protein synthesis, gene expression, and hormone synthesis and equilibrium [55]. Paul and Begum [58] reported that aqueous extracts of *A. mexicana* inhibited germination of Lentil (*Lens culinaris*). Therefore *A. mexicana* may similarly affect the germination of several plant species growing in the ecosystem.

### 3.2. Effects on Root and Shoot Length

Root growth is characterized by high metabolic rates and, for this reason; roots are highly susceptible to environmental stresses such as allelochemicals in soils [18]. Normal plant cell growth and morphogenesis requires regulation of the concentrations of hormones such as auxins and gibberellins [59]. Some of allelochemicals disrupts hormone equilibrium. For instance they may inhibit polar auxin transport leading to a disturbance in normal auxin levels and resulting in the induction of lateral roots and the suppression of ageotropic growth [60]. The contact of phenolic acids with the root cell membrane leads to depolarization, an efflux of ions, and a reduction of hydrolic conductivity, water uptake and net nutrient uptake [61]. Moreover, allelochemical inhibit root elongation and cell division and enlarge thickness of roots due to the inhibition of root longitudinal growth [51]. The allelochemical also initiates a series of reactive oxygen species (ROS) in root meristem which inactivate enzymes, damage vital cellular organelles in plants, and destroy membranes by inducing the degradation of pigments, proteins, lipids and nucleic acids which ultimately results in death of the root system [62] [63]. It were also significantly decreased with the increase of both root and leaf extracts concentration of *A. mexicana* [34]

[64]-[66]. Therefore, *A. mexicana* is known to possess allelochemicals that might induce reduced root and shoot growth in different plant species growing in their vicinity. However, the extent of such damage in different plant species requires scientific studies to substantiate.

### 3.3. Effects of Allelochemicals on Plants Fresh and Dry Weights

Decrease in plant growth caused by allelochemicals subsequently decreases fresh and dry weights. Allelochemicals reduce plant water potential [37] and inhibits minerals and ion uptake by plants [20] and reduces fresh weight. Interference with plant water balance is one of the mechanisms of action of *p*-hydroxybenzoic acid causing a reduction in plant growth. Studies have shown that soybean growth was reduced and water potential lowered with high concentrations of *p*-hydroxybenzoic acid [37]. Allelochemicals inhibits protein and carbohydrates synthesis, which in-turn reduce plant growth and weight [15]. Moreover, Einhellig and Rasmussen [67] found that decrease in biomass of treated soybean by phenolic acids were associated with reduced chlorophyll content in leaves. Similarly, Alagesaboopathi [65] also reported the decrease in fresh and dry weights of sorghum upon treatment with different concentrations of *A. mexicana* leaf aqueous extracts. Thus, allelochemicals in *A. mexicana* may inhibit growth of plants.

### 3.4. Influence of Allelochemicals on Photosynthesis and Chlorophyll Contents in Plants

Allelochemicals inhibits photosynthesis and oxygen evolution through interactions with components of photosystem II (PSII) [38] [68]. Allelochemicals can affect the performance of the three main processes of photosynthesis: stomatal control of carbon dioxide supply, thylakoid electron transport (light reaction), and the carbon reduction cycle (dark reaction) [38]. Chlorophyll is among the molecules in photosystem involved in light reaction which can be affected by allelochemicals. Chlorophyll is the most important pigment for photosynthesis [69]. The chlorophyll *a* and *b* are essential pigments for the conversion of light energy (solar radiation) to stored chemical energy [70]. Photosynthetic potential of a plant is determined by chlorophyll contents and any changes are expected to bring about change in photosynthesis [71] [72]. Chlorophyll also gives estimation of the plant nutrient status because much of leaf nitrogen is incorporated in chlorophyll [72]-[74]. The amount of chlorophyll per unit leaf area in plant is an important indicator of the overall plant healthy condition [72]. Healthy plants capable of maximum growth are generally expected to have larger amounts of chlorophyll than unhealthy ones [73]. Allelochemicals may reduce chlorophyll accumulation by inhibiting chlorophyll synthesis and/or stimulating chlorophyll degradation [75]. Several studies reported the decrease in chlorophyll contents with increase in concentration of allelopathic phenolics (vanillic acid, *o*-hydroxyphenyl acetic, *p*-hydroxybenzoic acid, camminic acid, ferulic and *p*-coumaric acids) in rice cabbage, Chinese fir, *Echinochloa crus-galli* and *Chenopodium album* seedlings [19] [52] [76] [78].

## 4. Conclusion

Little information is available about the allelopathic effects of *A. mexicana* on the growth of important wild plant species such as those grown in the protected areas. However, allelochemicals from *A. Mexicana* may affect germination, growth and chlorophyll content of wild plant species. Therefore, as proposed by Makoi and Ndakidemmi [79], there is a need to explore the allelopathic potential present in diverse plant species growing in mixture so as to get full benefits of allelopathy in the ecosystem.

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