Allelopathic effect of *Datura stramonium* on the survival of grass and legume species in the conservation areas

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Abstract

Survival of Biodiversity in Tanzania has been threatened by invasion of Invasive Alien Species in different potential and valuable ecosystems. The spread of invasive (exotic or alien) species can have a serious impact on biodiversity and even cause the extinction of native species. The fact that invasive species may perish native plants through allelopathic effects has made greater attention to many scientists and conservationists to investigate and study the mechanism behind this natural plant strategy. Through the release of allelochemicals to the environment, *Datura stramonium* can manipulate partners, competitors and ecosystems as whole. Understanding well the mechanism used, its effects and losses caused by this plant will enable us to come up with proper and effective management ways to prevent further invasion for the sake of protecting our biodiversity and ecosystems which will guarantee their existence. This review explores the allelopathic effect of *D. stramonium* on the survival of grass and legume species in the conservation areas.

Keywords: Allelochemicals, Biodiversity, Inhibition, Invasive alien species, chlorophyll, Distribution

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Introduction

The word allelopathy has been defined as the inhibition or stimulation of any aspect of growth and/or development of one plant by another through the release of chemical compounds into the environment (Rice, 1984; Inderjit *et al*., 2005, Ghafarbi *et al*., 2012). These chemical compounds are commonly known as allelochemicals (Singh & Chaundhary, 2011). Allelochemicals are used by plants and micro-organisms to manipulate partners, competitors and ecosystems (Waseem, 1998). In other word, these allelochemicals are also known as allelochemics (An *et al*., 1998). The allelochemicals are often classified as secondary metabolites, which are produced as by-products of plant metabolic pathways (An *et al*., 1998; Makoi and Ndakidemi, 2012). The secondary metabolism products produced by plants function as chemical agents against plant pathogenic microorganisms, insects and survival of neighboring plants but they are not essential for a plant's survival (An *et al*., 1998; Ma *et al*., 2011). Allelochemicals enables some plants to reduce all level of competition from other plants. If species with allelopathic effects are introduced to a new community, they may replace native plants because of the harmful chemicals that the native inhabitants have never experienced (Callaway *et al*., 2005). Some plants are known to have inhibitory effects on seeds germination and seedling growth of other neighboring plants by either releasing allelopathic substances as exudates from living plant tissues or through decomposition of plant residues (Rice, 1984; Alexander *et al*., 2008; Maibam *et al*., 2011; Oseni *et al*., 2011; Butnariu, 2012).

D. stramonium (Plate 1) is among allelopathic plants reproducing by seeds encapsulated in spiny seed pods which are apple-shaped (Wilbur, 1987; Alexander *et al*., 2008). It is an annual poisonous plant grows to approximately 1.5 m high and it is characterized by solitary white, trumpet-shaped flower (Fatoba *et al*., 2001; Steenkamp *et al*., 2004; Richardson *et al*., 2007). This plant species falls under family Solanaceae (Waseem, 1998; Binev *et al.*, 2006). Furthermore, *D. stramonium* is known with different names across the world such as Angel's trumpet, Jimson weed, Devil's trumpet, Devil's weed, Thorn apple, Jamestown weed, Stinkweed, Locoweed, Devil's cucumber and Hell's Bells (Mahnaz *et al.*, 2011; Oseni *et al*., 2011).

Plate 1: A matured *Datura stramonium* plant growing in NCA. Source: Field survey, 2013.

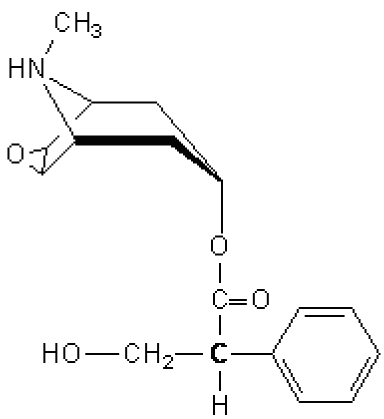
The origin of *D. stramonium* is not that much clear among conservationists although some botanists refer it to North America or Asia (Richardson *et al*., 2007). According to Mahnaz *et al.* (2011), the plant is native to Asia, but it is also found in the West Indies, Canada and in USA. This review explores the allelopathic effect of Jimson weed on the survival of grass and legume species in the conservation areas which are potential for maintaining the food chain in the ecosystem. The significant of this review is that it will provide scientific information regarding the damage, losses and growth inhibition of grass and legume species due to allelopathy condition created by invasive alien species. The information will increase knowledge to conservationists and enables them to determine the response of native plant community to environmental stress created by allelochemicals by closely investigating the properties of allelochemicals released by these species to the environment. There is a need to understand how allelochemicals from invasive species exudates to the vicinity and to what extent they can damage the growth parameters of native species. Selection of control techniques can be more appropriate if we have reliable information regarding the allelopathic mechanism used by this invasive species.

Allelochemicals found in *D. stramonium* that has allelopathic effect on the survival of native plants

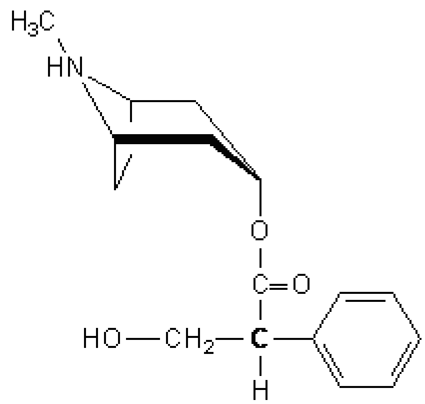
D. stramonium contains allelochemicals which inhibits growth of associated plant species through allelopathic mechanism. According to Maibam *et al*., (2011), this plant is a rich source of alkaloids. Moreover, it has been reported that all *Datura species* contain atropane alkaloids such as scopolamine, hyoscyamine and atropine (Figures 1 and 2), primarily in their seeds and flowers (Oseni *et al*., 2011). In addition, Shonle and Bergelson (2000) examined the presence of two major alkaloids; scopolamine and hyoscyamine in the leaves of *D. stramonium* and they found that both alkaloids came under active selection. The production of hyoscyamine and scopolamine in *D. stramonium* has been investigated in the different plant organs and at different stages of their life cycle. However, the investigation which aimed at identifying chemical compounds present in *D. stramonium* examined that the maximum contents of hyoscyamine and scopolamine are found in the stems and leaves of young plants, hyoscyamine being always the predominant component (Mirald *et al*., 2001). Allelochemicals from *D. stramonium* are very toxic when ingested by human or livestock but some of them are believed to treat some lethal diseases such as cancer. In Morocco, this plant is used traditionally as a healing medicine whereby the leaves and flowers have been used in the treatment of Asthma (El Bazaoui *et al*., 2011). The atropine and related alkaloids have been also used in Japan for the treatment of gastrointestinal diseases, cardiopathy and Parkinson's disease (Takahashi *et al*., 1997). Yet, it has been demonstrated that *D. stramonium* aqueous leaf extract induced oxidative stress in different human cancer cell lines (Iman *et al*., 2011). Another investigation carried out by Hussain *et al*. (2011) verified that the ether extract of *D. stramonium* has antitumor activity and exerts its activity by inhibiting mitosis of cancer cells. One of the toxic components found in *D. stramonium* being tropane belladonna alkaloids (Mahnaz *et al.*, 2011). Tropane alkaloids are allelochemicals found in *D. stramonium* and they are assumed to play resistance role against herbivory (Shonle and Bergelson, 2000). Other research findings have demonstrated that Jimson weed (*D. stramonium*) contains alkaloids such as atropine and scopolamine, which can cause anticholinergic toxicity (Bontayan, 2010). Some scientific studies have reported that *D. stramonium* extract is particularly rich in alkaloids and the alkaloids content of this species have been emphasized by the phytochemical investigators dealing with the biochemical composition of various parts of the plant (Adekomi *et al*., 2011). Through these scientific investigations, several alkaloids including their chemical structures have been quantified and identified from extracts prepared from seeds, leaves, shoot/stem and roots of *D. stramonium*.

It has been reported that sixty-four tropane alkaloids have been detected in *D. stramonium* plant and two new tropane alkaloids, 3-phenylacetoxy-6, 7-epoxynortropane and 7-hydroxyapoatropine have been identified (Maibam *et al*., 2011). In another study, sixty seven tropane alkaloids were identified in the organs of *D. stramonium* L. by Gas Chromatography /Mass Spectrometry. Among those alkaloids, nine new tropane alkaloids were tentatively identified; 3,7-dihydroxy-6 propionyloxytropane, 6,7-dehydro-3-tigloyloxytropane, 3-tigloyloxy-6,7-epoxytropane, 3,7-dihydroxy-6-(2′-methylbutyryloxy)tropane, 6,7-dehydroapoatropine, 3-(3′-methoxytropoyloxy)tropane, 3-tigloyloxy-6-isobutyryloxy-7-hydroxytropane, 3-tropoyloxy-6-isobutyryloxytropane and 3β-tropoyloxy-6β-isovaleroyloxytropane (El Bazaoui *et al*., 2011). According to Alexander *et al*. (2008), tropane alkaloids present in *Datura* species are hyoscyamine, atropine and scopolamine, whereby the highest alkaloid concentration being found in seeds. In other case regarding toxicity of *D. stramonium*, it was reported that six patients were admitted to the hospital at Maryland, United States in July 2008 after ingesting Jimsonweed accidentally. After investigation, atropine and scopolamine were detected in leftover stew that believed to contain a part of plant from *D. stramonium* by Liquid Chromatography-tandem Mass Spectrometry. Not only had those but also, chaconine and solanine (Figure 3); glycoalkaloids which are normally present in potatoes were also detected (Bontayan, 2010). On the other hand, Butnariu (2012) found that *D. stramonium* has a rich alkaloid spectrum and apart from scopolamine, which is the main alkaloid, it also contains other chemical compounds such as atropine, hiosciamine and teloidin (Figure 4). Although many allelochemicals have been extracted and identified from *D. stramonium*, phytochemical investigators believe that there are still many other chemicals which have not yet identified. This is due to the fact that new chemicals are still identified by plant scientists and continue to add to the list of chemicals found in *D. stramonium* plant. Some scientists reported that the some allelochemicals become active and released only depending on environmental factors like soil property and weather condition of the area. For this reason, there might have chance to discover and identify more chemicals in *D. stramonium* growing in various areas with different weather condition. Therefore, further studies should also focus on the isolation and identification of all chemicals from aqueous extracts of all organs of *D. stramonium* using modern chemical analysis.

Chemical structure of chemical compounds found in *D. stramonium*

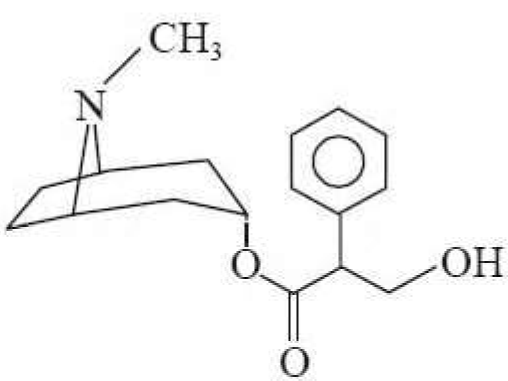


scopolamine

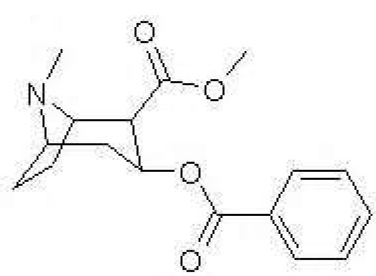


hyoscyamine

Figure 1: Allelochemicals released to the environment by *D. stramonium* that affects growth of neighbouring plant species.



Atropine



Narcotic cocaine

Figure 2: Allelochemicals found in *D. stramonium*.

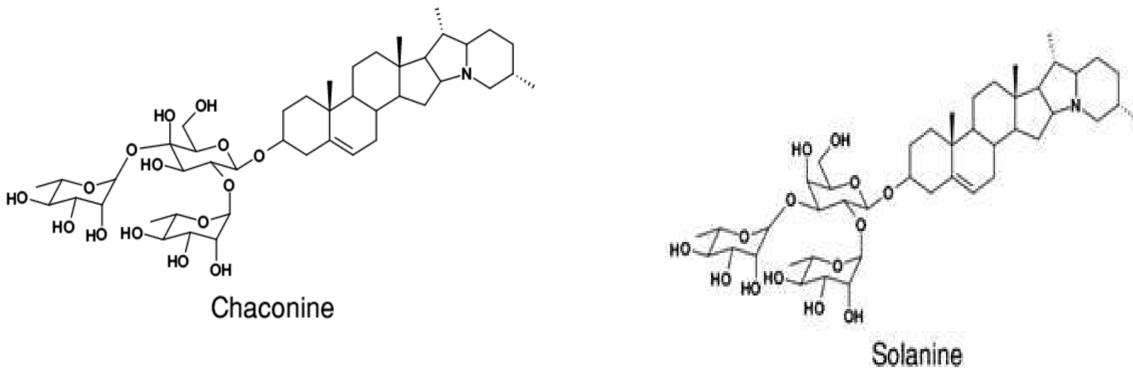


Figure 3: Allelochemicals found in *D. stramonium*.

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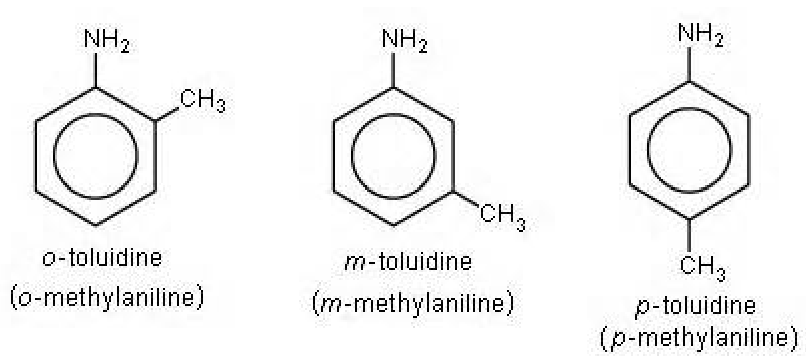

Figure 4: Allelochemicals found in *D. stramonium*.

Source:

https://www.google.com/search?q=chemical+sructures+of+alkaloids&source=lnms&tbm=isch&sa=X&ei=4WKUUoiCLOar4ATfq4HQCA&ved=0CAcQ_AUoAQ&biw=1366&bih=639.

Accessed on November 26, 2013.

Effect of *D. stramonium* to human being and animals

D. stramonium is abundantly available in our environment and therefore; acute intoxication may result from accidental ingestion of contaminated food such as vegetables and fruits or from ingestion with killing intention. The intoxication of *D. stramonium* is normally due to the fact that the plant possesses a high content of tropane alkaloids, such as atropine, scopolamine, and hyoscine, which may induce a pronounced anticholinergic effect (Diker *et al*., 2007). The toxicity of *D. stramonium* in grazing animals have been suspected by livestock owners and field veterinarians especially at time of drought or after ingesting freshly harvested maize contaminated with young plants (Nelson *et al*., 1982). It has been reported that the progressive atropine poisoning in pigs leads to a reduction of feed intake and growth, gastrointestinal motility and secretory activity, extreme mouth dryness, increased respiration and cardiac rate, pupil dilation and many other symptoms (Oseni *et al*., 2011).

D. stramonium has neurotoxic properties which are due to the presence of tropane alkaloids which contain a methylated nitrogen atom ($N\text{-}CH_3$) and include the anticholinergic drugs atropine, and scopolamine, as well as the narcotic cocaine (Figure 2) (Maibam *et al*., 2011). One of the organs of *D. stramonium* plant that believed to have high concentration of toxic chemical compounds is seed (Alexander *et al*., 2008; Maibam *et al*., 2011). The toxicity of seeds of *D. stramonium* is attributed by alkaloids but also to other components present in the seeds of plant (Bouzid *et al*., 2011). Seeds, leaves and stem of *D. stramonium* contain toxic hallucinogens that can cause delirious states or death (Oseni *et al*., 2011). In Maryland July 2008, the U.S. Centers for Disease Control and Prevention reported accidental poisoning resulting in hospitalization for a family of six who accidentally ingested *D. stramonium* used as an ingredient in stew (Bontayan, 2010). Additionally, four cases of *D. stramonium* intoxication seen at the Children's Hospital of Winnipeg, Manitoba, during the summer of 2006 were reported (Wiebe *et al*., 2008). Not only that but also another case concerning two patients (19 and 21-year-old men) with coma as a presenting sign of intoxication following intentional ingestion of *D. stramonium* seeds' tea were reported in Israel (Diker *et al*., 2007). These intoxication cases of *D. stramonium* to human being which have been reported in different regions show how poisonous this invasive plant species is whether ingested intentionally or unintentionally.

Various research findings have reported that almost all organs of *D. stramonium* including roots, stem, leaves and seeds contain chemicals which are poisonous to other plants, animals and human being (Wilbur, 1987; Maibam *et al*., 2011; Oseni *et al*., 2011). *D. stramonium* is recognized as a hallucinogenic plant that causes serious poisoning (Maibam *et al*., 2011). It contains chemical substances called narcotics which distort the brain and if taken by human being it usually causes hallucinations. Wilbur (1987) justified that all parts of the plant are poisonous, especially the seeds and leaves. Scientific investigation which was carried out by Adekomi *et al*. (2011), showed that the smoke extract of *D. stramonium* leaf had adverse and severe effects on the histology of the heart, liver, lungs, kidneys and testes of male Sprague Dawley rats when compared with the control animals. In some parts of Europe and India, *D. stramonium* is a popular poison for suicide and murder (Oseni *et al*., 2011). Although *D. stramonium* cause serious poisoning to animals and other plants, more studies are required to investigate the chemical properties of its toxic allelochemicals to establish if they can be used to eradicate destructive insects and weeds that destroy both food and commercial crops. Beneficial extraction of chemicals from *D. stramonium* as herbicides or insecticides can serve as one of the methods to control this invasive species.

Effects of invasion and spread of *D. stramonium* in the ecosystem

The spread of Invasive Alien Species (IAS) is now recognized as one of the greatest threats to the ecological and economic well being of the planet (IUCN, 2001). Not only that but also the IUCN (2001) pointed out that these species are causing enormous damage to biodiversity and the valuable natural agricultural systems upon which we depend. Some of native plant species in an area can undergo extinction because of the competition against invasive alien species commonly known as weeds (Hoeck, 2010; IUCN. 2011; Runyoro *et al*., 2011). Weeds are unwanted and non-economic plants that compete with crop for survival and reproduction (Hassannejad *et al*., 2013). Competition for resources is a key process that shapes plant communities (Dostal, 2011). Invasive alien species can transform the structure and species composition of ecosystems by suppressing or excluding the native species for example through allelopathy (IUCN, 2001). One of the mechanisms involved in the success of some exotic plants may be the release of harmful allelochemicals to the environment that affects the members of recipient plant community (Ayub *et al*., 2012). In plants, allelopathy is regarded as a natural strategy protecting plant against environmental enemies and competing plants (Razavi *et al*., 2011). For effective control, conservationists require comprehensive and mechanistic understanding of the degree in which intra and inter-specific competition control invasive and native plants growth (Berger *et al.*, 2008; Mangla *et al.,* 2011). This is important in monitoring productivity of the ecosystem otherwise the invasive alien species particularly those which are unpalatable to herbivores may rapidly colonize habitats and eventually cause rangelands degradation if effective control will not be employed (Runyoro *et al*., 2011). However, few studies to evaluate the increasing threats posed by alien plants particularly *D. stramonium* in protected areas in Tanzania have been reported. However, their distribution and extent of invasion in many areas are not clearly documented and hence difficult to control them. There is a need to map the distribution of *D. stramonium* and other invasive species in both conservation and protected areas. This will help to clearly state and document the rate of spread and the size of the ecosystem which have been infested by particular invasive species.

Effects of allelochemicals on leaf chlorophyll content, shoot and root elongation of native plant species

Chlorophylls are biomolecules which act as core component of pigment-protein complexes embedded in the photosynthetic membranes and play a major role in photosynthesis process (Siddiqui and Zaman, 2005). However, a plant's photosynthetic potential is directly proportional to the quantity of chlorophyll present in the leaf tissue (Schlemmer *et al.*, 2005). Furthermore, it has been reported that the allelochemicals produced by invasive species affect the photosynthesis and plant growth by destroying the chlorophyll (Peng *et al.*, 2004). Various studies have shown that, allelochemicals released by allelopathic plants do have negative effects on leaf chlorophyll content of neighbouring plant species (Oyerinde *et al*., 2009). The action of allelochemicals affects large number of biochemical reactions of target species resulting in alteration of different physiological functions (Gniazdowska and Bogatek, 2007). The allelochemicals released to the environment by poisonous plant species, have significant effects on neighboring plants by reducing the rate of photosynthesis and respiration processes (Gniazdowska and Bogatek, 2007). Allelochemicals leaching from plants with phenolic property may partially block the biosynthetic pathway of chlorophyll or stimulate the degrading pathway of chlorophyll and reduce photosynthesis process (Siddiqui and Zaman, 2005). Leaf chlorophyll content is a fundamental parameter in understanding the response of the plant to the environment in which it inhabits (Schlemmer *et al*., 2005).

Various scientific studies have pointed out that invasive species release allelochemicals which have negative effects on root and shoot elongation of neighboring plants (An *et al*., 1998; Burhan and Shaukat, 1999). *D. stramonium* as invasive alien plant species contains a series of allelochemicals; alkaloids including atropine (d–1–hiosciamine), hiosciamine, and scopolamine (Butnariu, 2012), which inhibits the growth and development of roots and shoots of other associated plant species (An *et al*., 1996). The allelochemicals can reduce cell division or auxin that induces the growth of shoot and roots (Gholami *et al*., 2011). Furthermore, allelochemicals affects the root system of the plant through reduction in shoot extension, number of roots, curling of the root axis, swelling or necrosis of root tips and lowered reproductive capacity of the plant (An *et al*., 1998). Allelochemicals such as phenolic compounds (benzoxazolin-2(3H)-one (BOA) and cinnamic acid) inhibit root and shoot length (Hussain and Reigosa, 2011). Growth inhibition caused by these allelochemicals may probably be due to its interference with the plant growth processes (Gholami *et al*., 2011). Allelochemicals released to the environment can either inhibit shoot/root growth, nutrient uptake, or may attack a naturally occurring symbiotic relationship thereby destroying the plant's source of a nutrient. Further studies are required to determine the allelopathic behavior of *D. stramonium* under field condition. Furthermore it is important to be familiar with the toxicity of allelochemicals, their quantity and effectiveness in the soil that suppress neighboring plants. This will help conservationists and phytochemical investigators to understand clearly the extent in which grass and legume species will be damaged if allelopathic plant species will not be prevented and/or eliminated. In advance, studies should be conducted to investigate the extent of damage in root and shoot systems of grass and legume species when exposed to the environment occupied with allelochemicals. This will help to predict the long-term effects of allelochemicals in the plant community if serious efforts will not be in place to stop further invasion of *D. stramonium* in ecosystems.

Conclusion

The review outlines the allelopathic effects of *D. stramonium* on the growth and survival of other neighbouring plant species particularly grass and legume species. The importance of mapping the distribution of *D. stramonium* is highlighted as this is important in establishing appropriate control measures in conservation areas.

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