

Allelopathy, Allelochemical and sustainable development in the field of agriculture.

Arnab Chakraborty¹, Dr. Puja Kumari Jaiswal²

¹Research Scholar, Department of Botany, Radha Govind University, Ramgarh, Jharkhand.

²Assistant Professor, Department of Botany, Radha Govind University, Ramgarh, Jharkhand.

Abstract:

Allelopathy refers to the direct or indirect chemical effect of one plant on another through the release of secondary metabolites known as allelochemicals into the environment. In agriculture, this natural ecological phenomenon has gained significant attention as a sustainable alternative to synthetic herbicides, pesticides, and fertilizers. Allelochemicals such as phenolic acids, terpenoids, alkaloids, and flavonoids are released through root exudation, volatilization, leaching, and residue decomposition, influencing weed germination, pest activity, and soil microbial dynamics. The integration of allelopathic crops like rice, wheat, sorghum, sunflower, and rye into farming systems can suppress weeds, reduce pathogen incidence, and improve nutrient cycling without degrading soil health or contributing to chemical residues. This aligns with the core objectives of sustainable development in agriculture: enhancing productivity, conserving biodiversity, minimizing environmental pollution, and reducing input costs for farmers.

Keywords- Allelopathy, Allelochemicals, Volatilization, Sustainable development, Flavonoids.

1. Introduction:

Allelopathy, a common biological phenomenon by which one plant released biochemical that directly influence the growth, survival, development, and reproduction of other plants. The word Allelopathy was first coined by Hans Molisch (1973), the plant physiologist, of university of Vienna, Austria. Allelopathy derived from two Greek word "allelon or allele" that mean mutual or each other and "pathons" that means suffering or to suffer. The biochemical released by plants known as Allelochemicals, have very prominent beneficial or detrimental effects. Plants grow, compete with each other for survivals and invisibly show a biochemical communication with each others. An allelopathic effect was first reported from alfa-alfa and the first biochemical was extracted from Walnut. Theophrastus, known as "the father of botany," wrote in his botanical works approximately 300 B.C. about how chickpeas "exhausted" the soil and destroyed weeds. This was the first mention of weed and crop allelopathy. (Khalid, Ahmad, & Shad, 2002). The International Society of Allelopathy (IAS) defined allelopathy as chemical interactions among plants and other organisms, excluding herbivores (Weir, Park, & Vivanco, 2004). Allelochemicals are mostly "secondary metabolites," which are produced by microbes, plants, and animals but are not required for basic (primary) metabolism. Instead, they serve ecological purposes to balance biotic and abiotic pressures. Allelochemicals have an impact on the physiology, growth, behavior, and life history of other creatures.

World’s population is increasing day by day, and this explosion caused food insufficiency. Tillable land and resources are limited in this world, accepting all threads of plants disease, pest control, water management, environment pollution and weeds, it is challenging for the crop harvesting world to fulfill the needs of peoples. Global crop production facing extreme climate change, irregular rainfall, and increasing in temperature resulting a reduction in crop production. Pests are usually responsible for the destruction and reduction of crops by 10–40% through competition for light, water, minerals, space, and sunlight (weeds) and tissue dilapidation (pathogens) (Fried et al. 2017).

Fortunately, allelochemicals provide us some short of extra luxury to control the invasive spices and pest management that enhance the rate of crop production with a sustainable management approach. Allelochemicals as natural and green herbicides can also substitute the disastrous chemical weedicides with organic allelopathic ones. Indeed, the allelopathic phenomenon may be used to embark upon these tribulations (Bhadoria 2011).

Allelopathy: - Rice (1974) defines Allelopathy is defined as any direct or indirect effect that a plant, including microorganisms, has on another by producing chemical compounds that leak into the environment and subsequently affect the growth and development of nearby plants. It encompasses reciprocal biochemical interactions that are both stimulative and inhibitory. As a result, the term "allelopathy" may be problematic. At a lesser dosage, substances that have been shown to impede the growth of one species may promote the growth of another or the same species. (Rice, 1984; Putnam & Tang, 1986).

Types of Allelopathy: - Aldrich (1984) describe two types of allelopathy-
Forms of Allelopathy: -

Types of Allelopathy	
True type	Functional type
<p>True allelopathy means when plants release biochemical compounds, toxic in nature and affect other plants in their natural form. Example- Juglone, an allelochemicals released by Black walnut (<i>Juglans nigra</i>), affects in plants growth.</p>	<p>In this case microorganism transferred chemical compounds released by plants into toxic compounds that’s effects others plants. Example- Quack grass releases chemical compounds that are not initially toxic. When these compounds mixed with soil, microorganisms transformed them into Ethylene, which show prominent inhibitory affects in growth of Maize plants.</p>

- **Auto allelopathy-** Intraspecific in nature means a plant species release toxic chemicals that inhibits plants belongs to same species. e.g. *Parthenium sp.* show adverse effects on its parent species like Wheat.
- **Allo allelopathy-** Allelochemicals released by plants adversely affects the growth and developments of other plants. e.g. Sunflower, Maize, many weeds, broad beans common beans, etc.

- **Concurrent or Direct allelopathy-** The instantaneous direct effect of released toxin from the living plant to another growing in the vicinity. It is also called “living plant effect”. e.g. Sorghum suppresses many weeds in growing in the vicinity.
- **Residual allelopathy-** Plant residue may interfere with the emergence and growth of the subsequent and neighboring plants through its allelochemicals. Therefore identification of plant species with residual allelopathy and characterization of their species-specific adverse effects were studied in a greenhouse experiments. (Syed et al., 2015).

Allelopathy can also be categorized as following-

- a. Inhibitory Allelopathy – Suppresses the germination and growth of the plants.
- b. Stimulatory Allelopathy – Promotes growth of the plants at low concentrations of the chemicals.

➤ It is the effect obtained on the plants growing in succession from the decaying

Allelochemicals: - In the process of allelopathy, various biochemicals, non-nutritive substances produce and released from donor plants to environment, that directly affects neighboring organisms. Allelochemicals can influence both living (biotic) and non-living (abiotic) components of the soil environment.

Liberation of allelochemicals- According to Rice (1984) and Putnam (1985), there are four ways in which the chemicals are released-

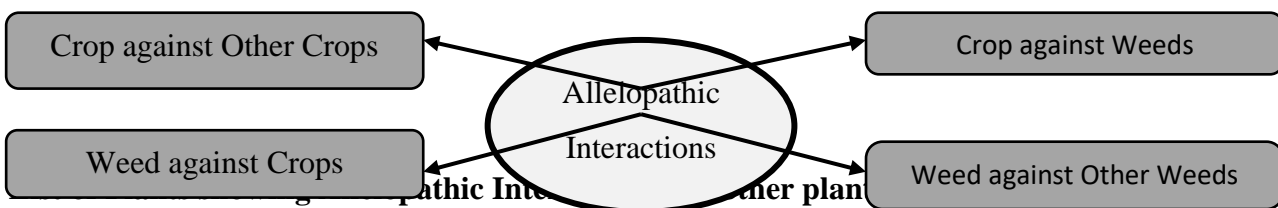
- A.** Volatilization- Allelopathic trees have tiny holes in their leaves that allow a chemical to be released as a gas. The poisonous substance is absorbed by other plants, which die.
- B.** Leaching- Plant leaves fall to the soil with storing of various chemicals, as they decompose large amounts of plant metabolites are transported from aerial plant parts by rain, dew, mist, or fog as aqueous solutes, a process known as leachation.
- C.** Exudation- Through their roots, certain plants discharge protective compounds into the soil. The adjacent trees' roots absorb the discharged pollutants. Other plants are selectively poisoned by exuding chemicals. Exudates typically contain a variety of phenolic chemicals that tend to impede development.
- D.** Residue Decomposition- Allelopathic substances are also released by old plant branches, leaves, and barks that have become litter or residue. Allelochemicals are released into the environment when weathering or soil bacteria break down the leaves and other plant parts that fall to the ground.

Types of Allelochemicals- According to the structures and properties, Allelochemicals classified into (i) water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes, and ketones (ii) simple unsaturated lactones (iii) long-chain fatty acids and polyacetylenes (iv) quinines (benzoquinone, anthraquinone and complex quinines) (v) phenolics (vi) cinnamic acid and its derivatives (vii) coumarins (viii) flavonoids (ix) tannins (x) steroids and terpenoids (sesquiterpene lactones, diterpenes, and triterpenoids) .

Chemical Groups	Examples	
Alkaloids	Benzyloisoquinoline Alkaloids-	Morphine, Codeine, Papaverine
	Pyrrolizidine alkaloids-	Senecionine, Echinatine

	Imidazole alkaloids:-	Caffeine, Theobromine, Theophylline
	Tropane Alkaloids:-	Nicotine, Cocaine, Atropine
Terpenoids	Monoterpenes:-	Limonene, Menthol, Pinene, Terpinolene, Citral
	Sesquiterpenes:-	B-Phellandrene, A-Humulene, Caryophyllene, Bisabolol
	Diterpenes:-	Abietic Acid, Cafestol,
	Triterpenes:-	β-amyrin, lupeol, betulin, ursolic acid
Phenolic Compounds	Flavonoids:-	Kaempferol, Quercetin, Luteolin, Rutin, Anthocyanins (Delphinidin, Malvidin);
	Coumarins:-	Umbelliferone, Umbellulactone, Fraxetin, Scopoletin
	Lignins:-	Guaiacyl Lignin, Syringyl Lignin
	Tannins:-	Catechin, Epicatechin, Proanthocyanidins.
Flavonoids	Kaempferol:-	Quercetin, Anthocyanins: Malvidin, Petunidin, Peonidin
	Isoflavones:-	Genistein, Daidzein
	Flavonols:-	Myricetin, Quercetin
	Flavones:-	Apigenin, Luteolin
Glucosinolates	Sinigrin:	Allyl Isothiocyanate (AITC)
	Glucoraphanin:	Sulforaphane
	Glucobrassicin:	Indole-3- Carbinol
	Progoitrin:	Isothiocyanates And Nitriles

Forms of Allelopathic Interactions-



Sl No.	Name of the plants	Types of inhibition	Reference
01	<i>Sorghum halepense</i>	Germ length, germ weight and seed germination on <i>Pisum</i> plants.	Georgieya and Nikolova (2016).
02	<i>Eucalyptus globules</i>	Fresh and dry biomass	El-Rokiek and El-Din (2017)
03	<i>Lactuca sativa</i>	Seedling growth	Chon et al. (2003)
04	<i>Populus deltoides</i>	Germination percentage, root and stem height and dry biomass while higher concentration	Majeed et al. (2017)

05	<i>Trema micrantha</i>	Germination and early growth	Borella et al. (2014)
06	<i>Silene villosa</i>	Germination percentage, root shoot length and fresh and dry weight of root and shoot	Murad et al. (2016)
07	<i>Azadirachta indica, Santalum album, and Thespesia populnea</i>	Seed germination and seedling growth parameters	Neelamegam and Dhanusha (2013)
08	<i>Calotropis procera</i>	Root length, shoot length, fresh weight and dry weight	El-Khatib et al. (2016)
09	<i>Trifolium alexandrinum L</i>	Germination, morphological characteristics, photosynthetic pigments, and nutrients uptake	Ebrahimi et al. (2016)
10	<i>Euphorbia guyoniana</i>	Germination efficiency, plumule and radicle length	Nasrine et al. (2013)

Reference- Ain, Q., Mushtaq, W., Shadab, M., & Siddiqui, M. B. (2023).

Farming methods that satisfy present food and fiber demands while protecting natural resources for future generations are referred to as sustainable development in agriculture. It seeks to strike a balance between social well-being, environmental preservation, and economic productivity. Through techniques like crop rotation, organic farming, integrated pest control, conservation tillage, and agroforestry, sustainable agriculture encourages the effective use of resources including soil, water, and biodiversity. These techniques lessen reliance on artificial fertilizers and pesticides, preserve soil fertility, cut down on environmental pollution, and conserve water. By enhancing ecosystem stability and lowering greenhouse gas emissions, sustainable agriculture systems also increase climate change resilience. Additionally, by boosting farm productivity and guaranteeing farmers' long-term financial viability, they assist rural livelihoods. By encouraging environmentally friendly technologies and responsible resource management, sustainable agriculture contributes to food security, biodiversity conservation, and ecological balance. Thus, it plays a crucial role in achieving global sustainable development goals and ensuring a healthier future.

Allelopathy contributes significantly to the advancement of sustainable agricultural development by offering an eco-friendly method of managing resources and producing crops. Allelopathy is the term used to describe the biochemical interactions that occur between bacteria, plants, and other species when secondary metabolites called allelochemicals are released. These substances have the ability to affect nearby plants' and microbes' germination, growth, survival, and reproduction. Allelopathy provides a natural option for enhancing agricultural sustainability in modern agriculture, where an over-reliance on synthetic fertilizers, herbicides, and pesticides has resulted in soil deterioration, environmental pollution, and biodiversity loss. Rice, wheat, sorghum, sunflower, rye, and mustard are examples of allelopathic crops that release bioactive substances that inhibit weed development and lessen the need for chemical pesticides. In addition to reducing production costs, this natural weed control reduces the buildup of hazardous residues in soil and water bodies. Additionally, adding crop residues and allelopathic cover crops to farming systems improves soil fertility, nitrogen cycling, and organic matter content, all of

which promote soil health and production. By preventing the development of dangerous infections and lowering pest populations, allelopathic interactions can also support integrated pest and disease management and lessen the need for artificial pesticides. Allelopathic tree species can be carefully managed in agroforestry systems to maximize resource consumption and enhance ecosystem stability. Allelopathic plants are used in crop rotation and intercropping systems to support biodiversity, preserve ecological balance, and increase resistance to environmental pressures. Allelopathy also contributes to climate-smart agriculture by lowering greenhouse gas emissions from the production and use of agrochemicals. Allelopathy's promise in sustainable agriculture methods is further demonstrated by the creation of bioherbicides and biopesticides made from allelochemicals. Natural substances such as phenolics, terpenoids, alkaloids, and flavonoids have been shown to have potent inhibitory effects on weeds and diseases, making them useful instruments for environmentally friendly crop management. However, as excessive allelopathic effects can potentially adversely affect crop growth, successful allelopathy application necessitates a thorough understanding of species-specific interactions, ambient circumstances, and suitable management strategies. Therefore, to maximize the advantages of allelopathy while avoiding potential hazards, ongoing research and technical improvements are crucial. Agriculture may increase productivity, lessen its impact on the environment, improve soil health, and conserve biodiversity by incorporating allelopathic principles into sustainable farming methods. Because allelopathy promotes food security, environmental preservation, and long-term agricultural resilience in the face of growing global challenges like population growth, climate change, and the depletion of natural resources, it is a promising biological strategy that supports the objectives of sustainable development.

2. Conclusion

Allelopathy, the biochemical interaction between plants mediated by allelochemicals, offers a promising pathway toward sustainable agricultural development. These naturally produced secondary metabolites influence the germination, growth, and survival of neighboring plants, weeds, pests, and microbes, functioning as nature's own herbicides and growth regulators. In the context of escalating environmental concerns, soil degradation, and herbicide resistance, harnessing allelopathy presents a viable alternative to synthetic agrochemicals. Crops like sorghum, rice, wheat, and sunflower release allelochemicals that suppress weeds, reducing reliance on chemical weeding and lowering production costs. Similarly, cover crops such as rye and mustard can be integrated into crop rotations to provide natural weed and pest management, improving soil health and biodiversity. This directly supports key pillars of sustainable development: environmental safety, economic viability, and reduced chemical load on ecosystems. Moreover, allelochemicals can enhance resource-use efficiency. By inhibiting specific weeds, they minimize competition for water and nutrients, improving crop yield without expanding land use. Their selective nature also helps preserve beneficial soil microbiota, unlike broad-spectrum herbicides that disrupt microbial balance. However, challenges remain. The efficacy of allelopathic interactions depends on soil type, climate, microbial activity, and crop genetics. Over expression of allelochemicals may also cause autotoxicity or unintended effects on subsequent crops. Therefore, research must focus on identifying stable allelopathic cultivars, isolating and formulating potent allelochemicals, and integrating them into holistic weed management systems. In conclusion, allelopathy bridges ecological principles and modern agriculture. When strategically applied through crop breeding, intercropping, and residue management, allelochemicals can reduce chemical inputs, mitigate resistance issues, and promote

ecological balance. Thus, they serve as a critical tool for advancing sustainable agriculture — ensuring food security while safeguarding natural resources for future generation.

Reference: -

1. Khalid, Shahida & Tahira, Ahmad & Shad, Rabnawaz. (2002). Use of Allelopathy in Agriculture. *Asian Journal of Plant Sciences*. 1. 10.3923/ajps.2002.292.297.
2. Weir, Tiffany & Park, Sang-Wook & Vivanco, Jorge. (2004). Biochemical and physiological mechanisms mediated by allelochemicals. *Current opinion in plant biology*. 7. 472-9. 10.1016/j.pbi.2004.05.007.
3. Bhadoria PBS (2011) Allelopathy: a natural way towards weed management. *Am J Exp Agric* 1(1):7
4. Fried G, Chauvel B, Reynaud P, Sache I (2017) Decreases in crop production by non-native weeds, pests, and pathogens. In: *Impact of biological invasions on ecosystem services*, pp 83–101
5. Syed, Sairah & Khan, Muhammad & Al-Haq, Muhammad Imran & Siddiqui, Hussain & Qureshi, Rahmatullah & Fujii, Yoshiharu & Jammu, Azad & Kashmir,. (2015). *Sarcococca saligna* (Muell.-Arg.) Exhibits Residual Allelopathy. 65.
6. Ain, Q., Mushtaq, W., Shadab, M., & Siddiqui, M. B. (2023). Allelopathy: an alternative tool for sustainable agriculture. *Physiology and Molecular Biology of Plants*, 29(4), 495-511.
7. Acharya, S. S., & Rahman, A. (1997). Allelopathic effect of *Parthenium hysterophorus* Linn. on seed germination and seedling growth of *Cassia tora* Linn.
8. Singh, H. P., Batish, D. R., & Kohli, R. K. (2003). Allelopathic interactions and allelochemicals: new possibilities for sustainable weed management. *Critical reviews in plant sciences*, 22(3-4), 239-311.
9. Chou, C. H. (1999). Roles of allelopathy in plant biodiversity and sustainable agriculture. *Critical reviews in plant sciences*, 18(5), 609-636.