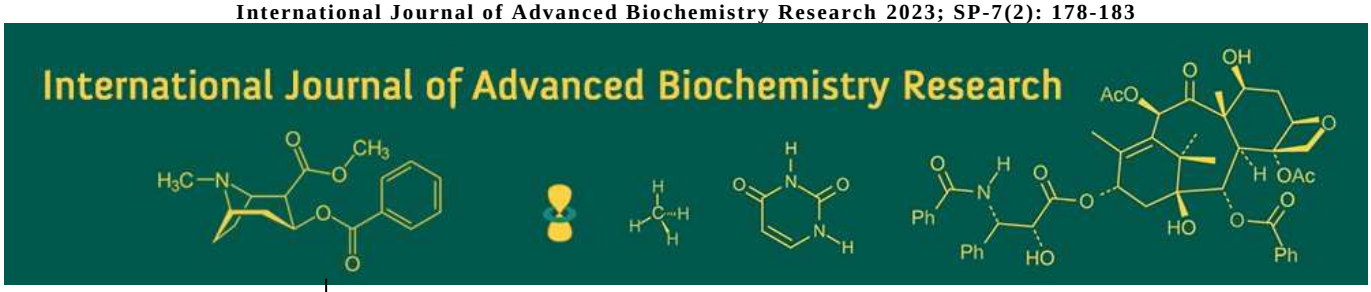

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Role of bio-stimulants in solanaceous vegetable crops: A review

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Abstract
Bio-stimulants have a crucial role in enhancing the growth, development and overall performance of nightshade family crops. Tomato, pepper and eggplant are important Solanaceous vegetables crops at worldwide due to their nutritional value and economic significance. Bio-stimulants, which are substances or microorganisms that stimulate plant growth and improve plant health, have emerged as valuable tools for sustainable agriculture. One of the key benefits of Bio-stimulants in Solanaceous vegetable crops is their ability to enhance nutrient uptake. These crops often require high levels of nutrients to achieve optimal growth and yield. Bio-stimulants can improve the efficiency of nutrient absorption by enhancing root growth. This results in healthier plants with improved vigor and productivity. Furthermore, Bio-stimulants can enhance the tolerance of nightshade family crops to environmental stresses. Bio-stimulants can help mitigate the negative effects of these stresses by promoting the synthesis of stress-related proteins and enhancing the plant's defense mechanisms. This leads to increased resilience and improved crop performance under adverse conditions. In addition, Bio-stimulants have been found to positively influence the quality and shelf life of Solanaceous vegetable crops. Bio-stimulants can also improve the post-harvest characteristics of these crops such as firmness, color and taste, thereby extending their shelf life and marketability. Overall, the role of Bio-stimulants in Solanaceous vegetable crops is significant and multifaceted. They contribute to improved nutrient uptake, enhanced stress tolerance and enhanced crop quality. Incorporating Bio-stimulants into the cultivation practices of Solanaceous vegetable crops can lead to sustainable and more productive agriculture.

Keywords: Bio-stimulants, solanaceous vegetable crops, sustainable agriculture, soil improvement, growth, yield and quality

Introduction
Nightshade family crops have an important role in human diet and to deal with malnutrition, particularly as sources of Vitamin A, C, E, thiamine, niacin and pyridoxine (Maharaj and Autar, 2006) [1]. Moreover this supplies many nutrients, they provide variety to diet and make the food attractive by their color, texture and flavor (Arindam Barman, 2020) [3]. A number of phytochemicals complexes which are found in Solanaceous crops *i.e* lycopene in tomato, capsaicin and capsanthin in chilli, solanine in brinjal and solasodine potato (Muthukumar and Selvakumar, 2013) [3]. Therefore, these are known as part of protective Foods (D. Singh, 2019) [4]. A plant biostimulant is a substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrients content (Sunitha *et al*., 2022) [4]. Plant Bio-stimulants are also designate commercial products containing mixture of such substances and/or microorganisms. Bio-stimulants exist in a number of formulations and unstable components but are generally classified into three main groups on the root of their starting place and content: humic substance (HS), hormone containing products (HCP) and amino acid containing products (AACP).

Functions of bio-stimulants
Plant biostimulant are stimulating plant responses and work in all weather conditions. It helps to stimulate plant immune system and increase Cation Exchange Capacity. It also helps to enhances fertilization and reduce leaching. Biostimulant can improve root development and build higher yields of the vegetable crops.

Moreover it improves taste and shelf-life of vegetable crop. It provides strength to vegetable crops to stand against drought and stress conditions. It helps to improve seed germination rates.

Various types of bio-stimulants

1. *Panchgavya*

Panchgavya is a unique blend of five cow-derived products namely cow milk, dung, ghee, curd, and urine follow steps involve in *Panchgavya* preparation:

1. Begin by thoroughly mixing 5 kg of cow dung and 0.5 kg of cow ghee. Ensure that the mixture is well combined. Allow it to sit undisturbed for a period of 3 days.
2. After the initial 3-day period, add 3 L of cow urine and 3 L of water to the previous mixture. Mix the contents thoroughly. Maintain the mixture for duration of 15 days, making sure to stir it regularly.
3. Following the 15-day period, introduce 2 L of cow milk, 2 L of cow curd, 2 kg of jaggery, 2 L of tender coconut water, and 24 ripe bananas to the mixture. Stir the mixture in the morning and evening.
4. Allow the mixture to mature for an additional 30 days. During this time, continue stirring it periodically.
5. After the 30-day period, the Panchgavya is ready for dilution and subsequent use.

Benefits of *Panchgavya*

Panchgavya help to develop bigger leaves and develop dense canopy of plant. It increase the photosynthetic efficiency of crops (Patel *et al.*, 2015) [7]. It help to produce maximum side shoots production and more branches formation (Choudhary *et al.*, 2017) [6]. Deeper root spreading behavior is observed in plant which treated with *Panchgavya* which helps in maximum intakes of nutrients and water from the soil as well deeper roots developed by the plants allow to withstand long dry period, which ultimately contribute to reduce the irrigation by 30% and ensure drought hardiness (Joshi *at al.*, 2020) [8]. It produced lean slippery film on leaves and stems, which ultimately affects on reduction of water evaporation.

Table 1: Effect of *Panchgavya* on Solanaceous Vegetable Crops

Crop	Concentrations	Effects	References
Tomato	3% at 25 DATP	Increase plant height, number of branches and early flowering	Parmar *et al.* (2020) [9]
	3% along with RDF	Improve fruit weight, number of fruit and dry matter	Nileema and Sreenivasa. (2011) [10]
Brinjal	5% with *jivaamrit* and 90% RDN	Enhance total yield	Rathore *et al.*(2023) [11]
Chilli	5% along with RDF	Enhance seed germination, root length, shoot length and number of leaf	Tamilarasi *et al.* (2017) [13]
	2.5% with neem oil 4 ml per liter alternatively at 15 days interval	Maximum plant height, number of branches, number of leaf per plant, leaf area, number of fruits, fresh weight of fruit and total yield	Mishra *et al.* (2015) [12]

2. Vermiwash

Vermiwash, also known as worm tea or worm juice, is a liquid extract obtained from vermicomposting. It is produced by passing water through a vermicompost bed containing earthworms (*Eisenia fetida* or *Lumbricus rubellus*). This organic liquid fertilizer is gaining popularity in agricultural practices, particularly in vegetable crop production.

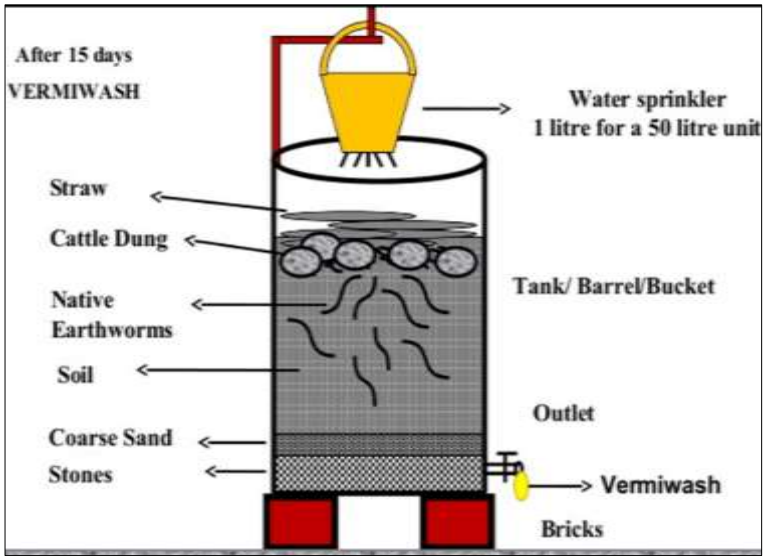


Fig 1: Procedure of varmiwash

1. Enhanced Nutrient Availability

Vermiwash is rich in essential plant nutrients including nitrogen, phosphorus, potassium and micronutrients. These nutrients are readily available in a soluble form, which can be easily absorbed by plant roots. The application of vermiwash to vegetable crops ensures a balanced nutrient supply which promoting healthy growth and development. Additionally, vermiwash contains beneficial microorganisms that aid in nutrient uptake and improve soil fertility (Fathima and Sekar, 2014) [14].

2. Improved Soil Structure
Regular application of vermiwash improves soil structure by enhancing its water-holding capacity, aeration and drainage. The organic matter present in vermiwash acts as a binding agent which promoting soil aggregation and reducing soil erosion. This improved soil structure creates a favorable environment for root development, leading to increased nutrient absorption and overall plant vigor (Fathima and Sekar, 2014) [14].

3. Pest and Disease Suppression
Vermiwash exhibits natural pest and disease control properties. The liquid contains enzymes and beneficial microbes that can suppress harmful pathogens including nematodes, fungi and bacteria. By applying vermiwash to vegetable crops, farmers can reduce the need for chemical pesticides thus promoting sustainable and eco-friendly farming practices (Sundararasu and Jeyasankar, 2014) [15].

4. Increased Crop Yield and Quality
The application of vermiwash has been shown to significantly increase crop yield and improve crop quality. The balanced nutrient supply improved soil structure and disease suppression properties contribute to enhanced plant health and productivity. Vegetables grown with vermiwash are often larger, tastier and have a longer shelf life which making them more marketable and economically viable for farmers (Sundararasu and Jeyasankar, 2014) [15].

Table 2: Effect of Vermiwash on Solanaceous Vegetable Crops

Crop	Effects	References
Tomato	Increasing concentration of vermiwash suppressed insect-pest population	Sayyad (2017) [16]
Brinjal	Enhanced plant height, number of leaves, number of flowers and fruits per plant	Sudararasu and Jeyasankar (2014) [15]
	Vermiwash when applied with bio-pesticide is a preferable option for the growth, productivity as well as management of *Lucinodes orbanalis* infestation	Mishra *et al.* (2014) [17]
Chilli	Maximum number of branches, number of fruits, Chlorophyll content and Ascorbic acid content was observed in 20% vermiwash application	Chavan *et al.* (2022) [18]

3. Cow urine
From time immemorial, India has been an agrarian country and the cow has been the backbone of our agriculture. Cow represents the Vedic values of selfness service, strength, dignity &non-violence. Cow occupies the highest place of honor in Indian civilization. Cow urine also referred as *Gomutra* which was explained in *ayurveda &* described in *Sushruta Samhita, Ashtanga Sangraha* and other *ayurveda* texts as an effective medicinal substance of animal origin with innumerable therapeutic properties. It is a rich source of macro, micronutrients and also have disinfectant properties thus purify the atmosphere & improve soil fertility.

Importance of cow urine
Cow urine helps in soil enrichment, soil fertility as well as soil productivity and it acts as an antimicrobial agent (Verma *et al*., 2017) [22]. It helps to plant overcome from micronutrients deficiencies (Ambika and Balakrishnan, 2015) [19]. Residual effect of cow urine is more pronounced in next cropping. It provides good environment in soil for beneficial living microorganisms and useful earthworms and acts as a natural insecticides and growth promoters in plants (Dharma, 2005) [20]. It reduces the cost of cultivation & increases the cost of production. Cow urine also helps in seed treatment for good germination (Kgasudi and Mantswe, 2020) [21].

4. Banana Pseudostem Enriched Sap
Banana pseudostem sap is obtained as a byproduct during extraction of fibre (Desai *at al*., 2016) [23] It is rich souce of Nitrogen, Phosphorus, Pottasium, Sulphur, Calcium, Magnesium, Iron, Manganize, Zinc, Copper, soluble sugars, phenols, amino acids and plant growth regulators like cytokinin and gibberellic acid (Dushyant Champaneri, 2021) [24].

Table 3: Effect of banana pseudostem enriched sap on solanaceous vegetable crops

Crop	Concentrations	Effects	References
Tomato	1.5% with 0.3% Silicic Acid	Maximum number of picking along with higher net return	Patel, (2019) [25]

5. Humic acid
Humic acid is a natural bio-stimulant that is derived from leonardite and it is the most concentrated organic material available today. Humic acid is an organic chemical which produced by decaying plants and animals residues by a process called “Humification”. Humic acid is one of the major components of humic substances which is dark brown in colour and the major constituents of soil organic matter is call humus that contributes to soil chemical and physical properties. Humic acid can also be found in peat, coal, many upland streams and ocean water. Elemental analysis of humic acid has shown that consists largely of carbon and oxygen (about 50% and 40% respectively) which also contains hydrogen (about 5%), nitrogen (about 3%), phosphorous and sulphur (Both less than 1%).

Benefits of Humic Acid
Humic Acid helps to induces high Cation Exchange Capacity (CEC) and increases water holding capacity (up to 4 times) of soil (Billingham, 2012) [26]. It can break down crop residues and increases aeration of soil as well as it helps to reduce soil erosion (Olk *et al*., 2017) [27]. Seed are treated with HA which helps to increases germination of seed. Seedling are treated with HA before transplanting result in better root growth and development (Canellas *et al*., 2002) [28]. It helps to enhances natural resistance against diseases. It provide feeds for microorganisms that recycle nutrients and produce antibiotics (Daniel *et al*., 2018) [29].

Table 4: Effect of Humic Acid on Solanaceous Vegetable Crops

Crop	Concentrations	Effects	References
Tomato	12% along with 100% RDF	Increase plant height, leaf area index, number of fruit per plant, fruit weight and total yield	Suman *et al.* (2017) [30]
Brinjal	10%	Maximum growth and yield parameters	Sam Ruban *et al.* (2019) [31]
Chilli	10% along with 75% RDF and bio-fertlizer	Increase plant growth, yield, and capsaicin content	Janaki *et al.* (2019) [32]
	10 kg per ha. With 0.1% micronutrient	Enhance number of branches, stem diameters, number of fruit per plant and total yield	Singh *et al.* (2019) [4]
Potato	600 kg per ha. with micronutrient	Superiority in plant height, number of stem per plant, number of tubers per plant, tuber weight, marketable, unmarketable and total yield	Zehra Ekin (2019) [34]

6. Sea Weed Extract

Seaweeds and seaweed extracts are used as a biofertilizers, soil conditioners and Bio-stimulants, infact the use of fresh seaweeds as a source of organic matter and fertilizer is very old in agriculture. Only recently, chemical analysis, immuno and bioassays have identified the many compounds which contribute to the plant growth promotion effect. Micro and macronutrients, special polysaccharides (alginates, lamanarin and carragheenans) sterols, N- containing compounds like betaines, and hormones are all recognized as a bioactive components.

What they do?

Sea weeds act on soil and plants. They can be applied on soils, in hydroponic solutions or as foliar applications.

In soil

Polysaccharides contributes. Gel formation, water retention, and soil aeration. Fixation and exchange of cations. Promotion of plant growth promoting bacteria.

In plants

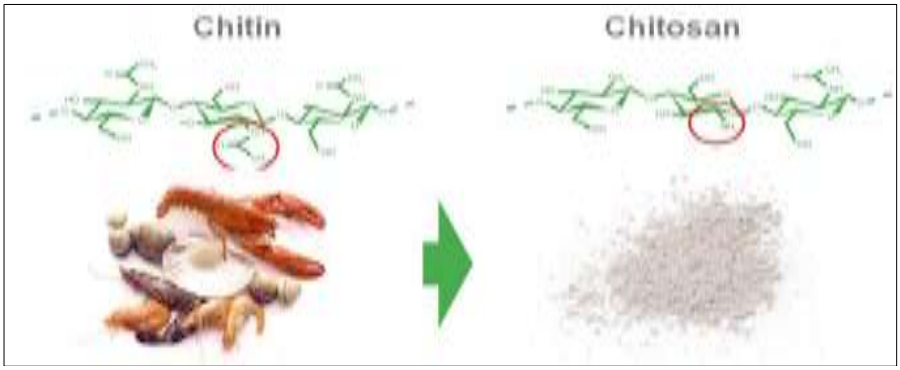
Nutritional effect. Impacts on seed germination, plant establishments and on further growth and development in association with hormonal effect.

Table 5: Effect of Sea Weed Extract on Solanaceous Vegetable Crops

Crop	Seaweed Extract	Effects	References
Tomato	*Ulva flexuosa* (100%)	Maximum Seed Vigour Index, fresh weight of seed, dry weight of seed and maximum seed germination percent with minimum time for germination	Chanthini *et al.* (2019) [35]
	Kappaphycus alvarezii (5.0%)	Enhance fruit quality parameters like ascorbic acid, acidity and TSS	Zodape *et al.* (2011) [36]
	Legume-derived protein hydrolysate (3 ml L^{-1})	Increase fruit TSS and lycopene content	Colla *et al.* (2017) [37]
Brinjal	2000 ppm	Improve plant height, number of leaf per plant and leaf area	Gawad and Osman (2014) [38]
Potato	*Gracilaria edulis* (10%)	Increase plant height, number of stem per hill, number of tuber per hill and total yield of tuber	Prajapati *et al.* (2016) [39]

7. Chitosan and other biopolymers

These natural substances have shown promising potential in enhancing plant growth, improving crop yield, and protecting plants against various environmental stresses. Chitosan, derived from chitin found in the exoskeleton of crustaceans, is known for its biocompatibility, biodegradability and non-toxic properties. When applied to vegetable crops, chitosan has been found to stimulate plant growth and development by increasing root and shoot biomass, enhancing nutrient uptake and improving photosynthetic activity. Additionally, chitosan has been shown to induce resistance against pathogens, such as fungi and bacteria, reducing the need for chemical pesticides.



Benefits of Chitosan and other biopolymers

Chitosan and other biopolymers provide protection to the plant against fungal pathogens (Sathiyabama *et al*., 2014) [40]. It helps to tolerance abiotic stresses *Viz*., drought, salinity, cold stress (Emami *et al*., 2017) [41]. It can be improve quality traits related to primary and secondary metabolisms. Stomatal closure induced by chitosan via an ABA-dependent mechanism.

Table 6: Effect of Chitosan on Solanaceous Vegetable Crops

Crop	Concentrations	Effects	References
Tomato	0.01 mg L^{-1}	Improve the germination of seed	Silvana *et al.* (2019) [42]

Conclusions

Now a day heavy use of chemical fertilizers reduce the productivity of soil and also impact on the human health, where Bio-stimulants are organic in nature which improve the soil productivity without any hazard on human health (Colla and Rouphael, 2015) [43]. *Panchgavya*, *jivamrit*, *beejamrit* and *amritpani* like Bio-stimulants are easily prepare at home from the cow by product which are cheap in nature and thus help in reduce cost of cultivation of vegetable crops (Kumar *at al*., 2019) [44]. It helps to improve biological and physical properties of soil. The circular nature of Bio-stimulants enhances resources efficiency and reduces nutrient losses (Karapouloutidou and Gasparatos, 2019) [45]. It has pesticide and insecticide properties which help to provide protection to the vegetable crops against different insects and diseases (Roberta *et al*., 2019) [46]. It improve growth, yield and quality of vegetables crops and other agriculture as well as horticulture crops (Rouphael *et al*., 2015) [43]. Mode of action of Bio-stimulants is different for root target and shoot target. On root target it help to improve water availability, nutrient availability, metal chelation, root ethylene and auxin level where on shoot target it help to Stomatal regulation, ROS scavenging, Osmoprotection and Membrane stability (Bagheri *at al.* 2018) [48].

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