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Research Article

Synergistic effects of silicon and seaweed extract on growth and leaf nutrient content of papaya cv Red Lady

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Abstract
Silicon is crucial in the process of absorbing and transporting nutrients to the plants, which in turn helps to decrease the toxicity of iron (Fe), aluminium (Al), and manganese (Mn). Plants can better endure drought and salt stress because it strengthens their tissues. Seaweed extracts serve as biostimulants and are considered vital nutrients for sustainable agriculture due to their organic nature and ability to decompose naturally. The present study aimed to compare the nutritional content and growth rate of papaya cv. Red Lady after being treated with silicon and seaweed extract. The papaya plants were moved to new spots 1.5m x 1.5m apart. A Factorial Randomised Block Design with nine treatments and three replications was used for the field experiments. At 6, 7, 8, and 9 months after replanting, silicon (potassium silicate at 0.3% and 0.5%) and seaweed extract at 3% and 5% were made through foliar application. The study showed that the plant's height (278.66 cm), stem width (174.8 cm), number of leaves per plant (33.17), petiole length (127.3 cm), and leaf length (123 cm) were all higher in T8 (SE 5%+PS 0.5%) than in T7 (SE 5%+PS 0.3%) or T5 (SE 3%+PS 0.5%). A study of leaf minerals in synchrony showed that the highest levels of N, P, K, S, Ca, and Mg were found in the leaves nine months after the crop was transplanted. Thus , using modest concentrations of silicon and seaweed extracts topically enhances growth, nutritional content in leaves, and resistance to biotic and abiotic stress, as well as Papaya Ring Spot Virus (PRSV), collar rot, and anthracnose.

Keywords: Growth, Leaf nutrient, Papaya, Potassium silicate, Seaweed extract

INTRODUCTION

Carica papaya is native to the tropical regions of Mexico; it appears to have been introduced into China as an Indian plant. Papaya is an important fruit crop, known as "common man's fruit" (Naveen Kumar *et al*., 2020). It has become one of the most popular tropical and subtropical fruits in the world. Papaya is one of the five main fruit crops grown in the tropics and is very important to business because it is very healthy and can be used as medicine. Plenty of minerals, fibre, phenolic acids, flavonoids, provitamin A, carotenoids, vitamin C, anthraquinones, tannins, and cardenolides can be found in this fruit (Ovando□Martínez and González□Aguilar, 2020). The total area of papaya in India is 1.49 million hectares and the state of Andhra Pradesh is India's largest producer of papaya, followed by Gujarat and Karnataka. Curiously, this fruit is unique in that it undergoes flowering and fruiting throughout the year. The papaya evergreen, fast-growing perennial tree with a short lifespan (Patel, *et al.,* 2021). Papaya is a species of three sexes: staminate, pistillate, and hermaphrodite (Harinder Singh and Anis, 2020). There is a great market demand for papain, which is found in unripe papaya fruit (Ashutosh, 2018). Pharmaceutical, leather, and textile industries all used papain (Patel *et al.,* 2021). Red Lady is a gynodioecious variety known among Indian herbs for its orange-red flesh, strong production capacity, excellent quality and long shelf life (Mitra and Sharma, 2020).

Papaya is susceptible to a range of abiotic and biotic stressors that impact both the quantity and quality of its fruit supply (Patel, *et al.,* 2020). Silicon is crucial for mitigating many abiotic and biotic stresses. This element is the second most prevalent in soil, behind oxygen, and makes up around 28% of the earth's crust. The process serves a crucial function in facilitating the absorption and transportation of nutrients, so guaranteeing a bountiful fruit harvest that remains stable over an extended period (Patel *et al.,* 2019). Silicon increases phosphorus availability by creating solidified tissue in plants and improves plant drought and salt tolerance. Seaweed extracts are organic, biodegradable and important nutrient source for sustainable agriculture. It is widely used as a biostimulant in plant management due to its growth-promoting and stress-relieving properties. These are microscopic algae that thrive in oceanic and shallow coastal waters, and on rocky coasts. It is a marine plant found along the ocean coast. Small algae that live on the bottom of rocks, shells and other debris (Raja and Vidya, 2023). It has many benefits for plant treatment, such as increasing yield, increasing nutritional quality, resistance to cold and stress, prolonging the postharvest period and increasing seed germination. Secondary metabolites produced by seaweeds have many biological properties, including antibacterial, antiviral, nematocidal, and anticoagulant properties (Caijiao *et al*., 2021). The seaweed-derived polysaccharides and oligosaccharides function as chelating agents, binding other components and generating a gel that efficiently contains water (Mahusook *et al*., 2021). Biostimulants found in different types of kelp also help plants deal with stress better, including drought, ion balance, oxidative stress, salt stress, osmotic stress, cold stress, temperature tolerance, high-temperature tolerance, cold tolerance, and heavy metal tolerance (Bisen, 2020). It acts as a chelating compound and soil conditioner and is considered a good natural fertilizer and chemical and medicinal preparations. The present research aimed to analyse the effect of silicon and seaweed extract on the Red Lady variety of papaya.

MATERIALS AND METHODS

An on-site experiment was carried out at the Horticultural Farms, Lovely Professional University, Punjab from 2022 to 2024 to assess the foliar application of silicon and seaweed extract on growth and nutritional composition of papaya cv. Red Lady. The study used disease-free and robust seedlings of the Red Lady cultivar of papaya, sourced from Punjab Agriculture University. The seedlings were relocated to raised beds, spaced 1.5 x 1.5 metres apart, in the second week of April. The trial used a factorial randomised block design, consisting of nine treatments and three replications. The treatments: T_0- Control, T_1 -Potassium Silicate 0.3%, T_2 – Potassium Silicate 0.5%, T_3 – Seaweed Extract 3%, T_4 – Seaweed Extract 3% + Potassium Silicate 0.3%, T_5- Seaweed Extract 3% + Potassium Silicate 0.5%, T_6 – Seaweed Extract 5%, T_7 -Seaweed Extract 5% + Potassium Silicate 0.3% ,T_8- Seaweed Extract 5% + Potassium Silicate 0.5% were used.

The plants in the experimental block were regularly fertilised with a consistent application of RDF 200g:200g:250g NPK per plant annually (Chawla and Sadawarti, 2022). The fertiliser was evenly administered at 2, 4, 6, and 8 months after transplanting. Application of silicon and seaweed extract were applied foliarly during the 6th, 7th, 8th, and 9th months after transplanting. Requisite plant protection measures were implemented throughout the study. The growth characteristics, including plant height (cm), stem girth (cm), number of leaves, petiole length (cm), and leaf length (cm), were measured four months after foliar treatment. To assess the nutritional levels in papaya leaves, samples were collected from healthy and mature leaves (specifically, the 6th leaf from the top) before and one month after applying Silicon and Seaweed extract to the foliage. The leaf nutrient content was estimated using several techniques like Wet digestion (Chromic acid) method was used to determine the Nitrogen content, while the Wet digestion (Diacid) method was utilised to determine the Phosphorus and Potassium content. The recorded data was analysed using OPSTAT software (Melnyk and Swink, 2016).

RESULTS AND DISCUSSION

Growth attributes

The growth attributes of papaya cv. Red Lady such as plant height(cm), plant height (cm), stem girth (cm), number of leaves, petiole length (cm), and leaf length (cm) were influenced by foliar application of silicon and seaweed extract are mentioned in Table 1.

Plant height(cm)

A notable disparity was detected in growth after the application of Seaweed extract and silicon by foliar spray, using various combinations. From the various treatments, the plants in the T_8(Seaweed extract 5% + Potassium silicate 0.5%) recorded the maximum plant height(278.66cm), followed by T_7 (269.83cm) and T_5 (265cm), respectively. The minimum growth values were observed under the treatment T_0 (Control).

Seaweed extracts include a high concentration of phytohormones, including auxins, cytokinins, and gibberellins. These phytohormones can regulate the process of cell division and elongation in strawberry plants (Rahimi and Abdollahi, 2022). Seaweed extract contains bioactive compounds and nutrients that promote cell elongation, increase nutrient absorption, and promote plant growth (Kumar *et al.,* 2020).

Stem girth (cm)

It was observed that plants under the treatment T_8 (Seaweed extract 5% + potassium silicate 0.5%) show the maximum stem girth(174.8cm) followed by T_7 (167.5cm) and T_5 (162.6cm), respectively. A minimum of 116.1cm of growth was observed in the Control.

Seaweed extract and silicon have been shown to support stem development by improving cell division, elongation, and overall growth patterns of root tissue in

Table 1. Papaya cv. Red Lady growth influenced by foliar application of seaweed extract and silicon

Treatments	Height of plants (cm)	Stem Girth (cm)	No. of leaves	Length of petiole (cm)	Length of leaf (cm)
T_0-Control	238.33	116.1	24.17	107.3	113
T_1- Potassium Silicate 0.3%	243.5	146.5	28.17	110.7	115.7
T_2-Potassium Silicate 0.5%	257	146.43	30.17	125.3	113.3
T_3-Seaweed Extract 3%	247.66	146.3	26.33	110.2	109.3
T_4-Seaweed Extract 3% +Potassium Silicate 0.3%	264.83	152.37	31.33	122.8	117.3
T_5-Seaweed Extract 3% +Potassium Silicate 0.5%	265	162.6	32	125.8	120.3
T_6- Seaweed Extract 5%	260.6	161.1	31.8	122.7	117.3
T7-Seaweed Extract 5% +Potassium Silicate 0.3%	269.83	167.5	32.5	127.3	121.7
T_8- Seaweed Extract5% +Potassium Silicate 0.5%	278.66	174.8	33.17	127.3	123
C.D	3.637	2.108	1.312	1.122	1.659
SE(m)	1.203	0.697	0.434	0.371	0.549

strawberries (El-Hagarey, *et al.,* 2021). Silicone helps strengthen cell walls and tissues, which increases hardness and promotes growth. Silicon also improves nutrition and transport, giving the fruit healthy, thick stems in Guava (Seif El-Yazal, *et al.,* 2022).

Number of leaves

The treatment with the most leaves per plant was T_8, which had 34 leaves. This was followed by treatment T_7 with 33 leaves per plant and treatment T_5 with 32 leaves per plant. A minimum of 24 was observed in the treatment T_0.

Auxins, cytokinins, and gibberellins are abundant plant growth regulators in seaweed extract. These regulators are crucial for controlling the growth and development of leaves. Additionally, seaweed extract provides essential nutrients, amino acids and trace elements that support photosynthesis and leaf metabolism (Elansary *et al.,* 2022). Silicon increases the strength and power of the plant, thus enabling the leaves to emerge from the fruit. Silicon strengthens cell walls, reduces stress and increases nutrient absorption, all of which results in healthy, rich leaves (Ghoname *et al .,* 2021)

Petiole length (cm)

The maximum petiole length of 127.3cm was recorded in treatment, followed by T_7 (127.3cm) and T_5 (125.8cm). A minimum of 107.3cm of growth was observed in treatment T_0.

Foliar application of potassium silicate resulted in papaya plants' more vigorous growth, with less stress to abiotic and biotic factors. Si has been shown to mitigate the negative effects of salinity in less salt-sensitive species as well as salt-sensitive species, such as cucumbers (*Cucumis sativus L.*)growth characteristics of cucurbit (bitter gourd (*Momordica charantia L.*) by lowering salt toxicity and increasing photosynthetic activity (Ghani, *et al.,* 2018).

Leaf length (cm)

The maximum leaf length was recorded in treatment T_8 (123cm) followed by T_7 (121.7 cm) and T_5 (120.3cm), respectively. A minimum of 113cm of growth was observed in the treatment T_0.

Various seaweeds contain iron and manganese, which improve photosynthesis and chlorophyll synthesis, ultimately positively impacting growth parameters (Ali *et al.*, 2021). *Ascophyllum nodosum* is one of the seaweeds that has been applied to tomato leaves, and it makes them grow more (Dookie *et al.*, 2021). Silicon has a significant function in promoting the antioxidant systems of plants, immobilizing harmful metals, and facilitating the intake of vital nutrients(Patel, *et al.,* 2019). Furthermore, under autotoxicity stress, using Si

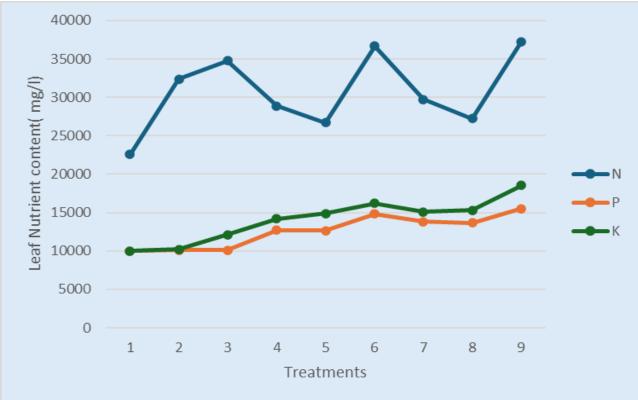

Fig .1. *Showing impact of silicon and seaweed extract on the nutritional content (NPK) of papaya cv Red Lady leaves*

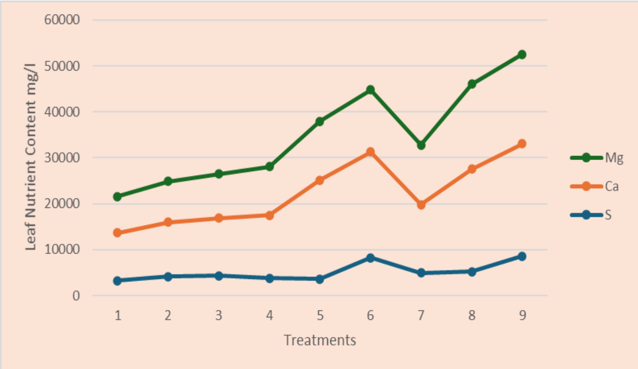

Fig. 2. *Showing leaf nutrient content (S, Ca, Mg) in leaves of papaya cv Red Lady*

has dramatically improved the leaf length and area in strawberries (Zhang *et al.,* 2020).

Leaf nutrient content (mg/l)

The use of seaweed extract and silicon treatments, alone or in combination, significantly influenced the nutritional composition (NPK) of the Red Lady papaya leaves. Fig 1 illustrates significant discrepancies after the use of seaweed extract and silicon by foliar spray. The highest amount of leaf nitrogen content, 37240mg/l was recorded in the treatment of $T_{8,}$ which was found to be par with treatment T_5(36680mg/l), respectively. The minimum leaf nitrogen content was observed in the treatment T_0(22560mg/l). Phosphorus content in the leaf was a maximum of 15520mg/l in treatment T_8 and was par with treatment T_5(14810mg/l). The minimum leaf phosphorus content of 10012mg/l was observed in the treatment T_0. The maximum potassium content in the leaves 18560mg/l was recorded in treatment T_8 and it was found to be a par with treatment T_5(16210mg/l). The minimum leaf potassium content10010mg/l was observed under the treatment $T_{0.}$

The uptake and transportation of nutrients such as N, P, K, Ca, and Mg are enhanced by silicon, which raises the leaves nutritional content (Patel *et al.,*2021). The extract of *Ascophyllum nodosum* raises the amount of chlorophyll and photosynthesis's efficiency while encouraging root growth (Rosário Rosa *et al*., 2021). Plants could absorb more phosphorus because silicon in the solution reversed its fixation, releasing phosphorus gradually and facilitating greater uptake (Javaid and Misgar, 2017).

The maximum sulphur content in the papaya cv Red Lady leaf was recorded in the treatment T_8(8546mg/l) followed by T_5 (8250mg/l). The minimum leaf sulphur content of 3230mg/l was recorded in the treatment T_0. The Red Lady's maximum leaf calcium content was recorded in Treatment T_8(24490mg/l) followed by T_5 (23040mg/l) Fig 2. The minimum leaf calcium content of 10420mg/l was recorded in T_0. The maximum leaf Magnesium content was observed in treatment T_8 (19530mg/l) followed by T_7(18520mg/l) and the minimum leaf magnesium content of 7896mg/l was recorded in the treatment T_0.

Seaweed extracts are an excellent source of essential nutrients such as N, P, K, Ca, and Mg as well as providing various organic components, trace elements and growth regulators for crop growth, increasing the leaf nutrient content(Muraleedharan *et al*., 2020). Biostimulants help plants' growth and development, as well as their physiological processes, biological traits, and food yield (Yao *et al.,* 2020). Adding seaweed extract to the leaves of *Solanum lycopersicum* and *Capsicum annuum* plants increases the chlorophyll content (Ali *et al.,* 2019). The application of seaweed extract significantly improves the vegetative growth, and leaf content of mineral nutrients in the 'Early sweet' variety of grape (Belal *et al.,* 2023).

The current study highlights the potential use of the seaweed extract and silicon for enhancing papaya cultivation. The results provide valuable insights for papaya growers and researchers aiming to use seaweed extract as a biostimulant to improve cultivation practices and meet market demand.

Conclusion

The present study's results indicated that applying silicon and seaweed extract to papaya cv Red Lady at various intervals after planting, under Punjab circumstances, positively affected growth and leaf nutritional content. Seaweed extract enriches the growth and plays a vital role in regulating leaf formation and expansion. Silicon was found to strengthen and increase nutrient absorption in the plants. Therefore, applying seaweed extract at a concentration of 5% along with potassium silicate at a concentration of 0.5% can significantly enhance the growth of papaya plants. The enhancement was evident in augmented plant height, stem circumference, leaf count per plant, petiole length, leaf length, and nutritional composition, including nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium.

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Conflict of interest

The authors declare that they have no conflict of interest.

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