

Biotic Resistance, Quality, and Storage Behavior of Potato (*Solanum Tuberosum* L.) As Influenced by Bio-Stimulants

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ABSTRACT:

The study was conducted at Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bangalore, to assess the impact of various bio-stimulants on the biotic resistance, quality, and storage behavior of potato (*Solanum tuberosum* L.) during the LI, 2022-23, and R, 2023. The experiment was designed as a randomized complete block design (RCBD) with nine treatments and three replications, using bio-stimulants such as humic acid, amino acids, seaweed extracts, and microbial consortia. The treatment combination of whole tubers + RDF + Humic acid at 2 mL L⁻¹ significantly enhanced plant resistance against pests and diseases. This treatment led to the lowest aphid and cutworm populations, reduced tuber moth infestation, and minimized the incidence of early blight, late blight, and bacterial wilt compared to the control—further, the same treatment combination improved tuber quality, viz., TSS and starch content. Additionally, it resulted in lower percentage of physiological loss of weight (PLW) and sprouting during storage under room temperature, with minimal tuber rot. In contrast, the control treatment recorded the highest pest populations, disease incidence and post-harvest losses. These findings suggest that the treatment comprising whole tubers, RDF, and Humic acid at 2 mL L⁻¹ effectively improves biotic resistance, quality, and storage behavior of potatoes under ambient conditions.

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INTRODUCTION

Potato (*Solanum tuberosum* L.), a member of the Solanaceae family, is one of the world's most important vegetable crops, ranking fourth in global production after wheat, rice, and maize (FAO, 2008). It is a reliable source of carbohydrates, vitamins, and minerals (El Banna *et al.*, 2006). The edible tubers consist of approximately 75-80 % water, 16-20 % carbohydrates, 2.5-3.2 % crude protein, 1.2-2.2 % total protein, 0.8-1.2 % mineral content, 0.1-0.2 % crude fats, and about 0.6 % crude fiber per 100 g fresh weight (Ezeikal *et al.*, 1999).

As a staple vegetable, potato tubers not only supply energy but also contribute dietary fiber, micronutrients, and bioactive compounds important for human nutrition and food security.

In recent decades, the concept of bio-stimulants has gained increasing attention in potato production. Bio-stimulants are defined as substances or microorganisms applied to plants or soils that stimulate natural processes to enhance nutrient uptake, stress tolerance, vigor, and quality (Du Jardin, 2015). Under potato cultivation, bio-stimulants can augment plants' resistance to pests and diseases by activating innate defense mechanisms, for instance by increasing the production of phytoalexins, enhancing structural barriers, and triggering induced systemic resistance (Khan *et al.*, 2004; Zhang *et al.*, 2013). Field and greenhouse research has shown that application of bio-stimulants improved plant health in potato, reduced crop losses from pathogens and stress, and enhanced tuber quality attributes (Rouphael & Colla, 2020).

Beyond disease resistance, bio-stimulants influence key quality and storage-related attributes of potato tubers. They have been found to modulate total soluble solids (TSS), starch content, dry matter, tuber size and shape, and nutritional composition, parameters which are crucial for marketability and processing suitability. For example, foliar applications of amino-acid-based bio-stimulants increased TSS (from approximately 18 to 28 %) and protein content (from approximately 2.11 to 2.76 %) in tubers, along with enhanced nitrogen, phosphorus, and potassium uptake (Abd El-Latif *et al.*, 2024). Other studies with seaweed extracts and humic substances observed increases in tuber macronutrient contents (e.g., K increased approximately by 1.26 g kg⁻¹ in early-crop tubers) and improved ionic ratios, contributing to tuber quality (Wadas & Dziugiel, 2020; Kolodziejczyk & Gwozdz, 2022). While not all studies show dramatic changes in all quality traits, the body of evidence supports a role for bio-stimulants in improving tuber performance under both optimal and sub-optimal conditions.

Moreover, the storage behavior of potato tubers is also substantially influenced by pre-harvest bio-stimulant treatments. Application of bio-stimulants has been linked to reduced physiological weight loss during storage, suppressed sprouting, improved firmness, and maintenance of nutritional attributes during storage, thereby increasing shelf life and reducing post-harvest losses (Badawy & Rabea, 2011; Du Jardin, 2015). Given that post-harvest losses remain a major constraint for potato value chains, especially in developing countries, this effect of bio-stimulants has significant practical importance.

As global agriculture moves toward more sustainable intensification, achieving higher yields and quality with a lower environmental footprint, the use of bio-stimulants in potato cultivation offers a promising strategy. Their ability to enhance nutrient-use efficiency, improve stress resilience (both biotic and abiotic), and improve tuber yield, quality, and storage behavior positions them as important components of integrated crop-management systems (Rouphael *et al.*, 2018; Li *et al.*, 2022). For instance, a flavonoid-based bio-stimulant tested on potato increased tuber yield by an average of 33% in controlled experiments and by approximately 5.2% across multiple commercial crops, also promoting larger tuber size

(Salvage *et al.*, 2024). Such advances suggest that integrating bio-stimulants into potato production can enhance productivity, improve product quality, and reduce losses, thereby contributing to food security, economic viability, and environmental sustainability.

In this context, the present study aims to investigate the effect of selected bio-stimulants on potato tuber yield, quality attributes (including dry matter, starch, nutrient content, and marketable tuber size), and storage behavior under the given agronomic conditions. The main objective is to evaluate the potential of bio-stimulants to improve potato production efficiency and post-harvest performance, and to provide recommendations aligned with sustainable vegetable-crop production systems.

MATERIAL AND METHODS

The experiment was conducted at the Zonal Agriculture Research Station, University of Agricultural Sciences, GKVK, Bengaluru, during *Rabi* 2022–2023 and *Kharif* 2023. The experimental block is situated at an altitude of 924 m above mean sea level between a latitude of 13° 05" North and longitude of 77° 34" East. The experiment has 9 treatments arranged in RCBD design with 3 replications. The treatments involved soil application of bio-stimulants *viz.*, T₁- whole tubers + RDF: Recommended Dose of Fertilizer (Control), T₂- whole tubers + RDF + Humic acid at 2 ml L⁻¹, T₃- whole tubers + Amino acid at 3 ml L⁻¹, T₄- whole tubers + RDF + Sea weed extract at 2 ml L⁻¹, T₅- whole tubers + RDF + Arka microbial consortium at 10 ml L⁻¹, T₆- cut tubers + RDF + Humic acid at 2 ml L⁻¹, T₇- cut tubers + RDF + Amino acid at 3 ml L⁻¹, T₈- cut tubers + RDF + Sea weed extract at 2 ml L⁻¹ and T₉- cut tubers + RDF + Arka microbial consortium at 10 ml L⁻¹. The whole and cut tubers of potato variety Kufri Himalini were planted in lines at 45 cm row-to-row and 20 cm plant-to-plant spacing. Soil was provided with 125: 100: 125 kg N:P:K ha⁻¹ and 25 t ha⁻¹ FYM before planting. The various bio-stimulants, *viz.*, Humic acid @ 2 ml L⁻¹, Amino acid @ 3 ml L⁻¹, Sea weed extract @ 2 ml L⁻¹, and Arka microbial consortia @ 10 ml L⁻¹, were applied to the crop at 30 and 60 days after planting at a rate of 1500 liters per hectare as a soil application. The following methods were followed for recording pests, diseases, and storage behavior observations:

Pest infestation

Aphid population was recorded per 100 compound leaves at 60 days after planting and reported as aphid count per plant.

For the cutworm population, the plants were inspected every 15 days, and the count was recorded by temporarily removing the topsoil around selected plants to count the cutworms; the count per plant was reported.

Potato Tuber Moth infestation during storage (%)

The number of infestation points per tuber and the number of infested eyes per tuber caused by potato tuber moth were counted at 30, 60, and 90 days after storage. The mean index of tuber damage was assessed using the method described by Sharaby and Fallatah (2019). The percentage of tuber damage was then calculated by using the following formula.

$$\text{PTM damage (\%)} = \frac{\text{Number of tubers damaged}}{\text{Total number of healthy tubers}} \times 100$$

Disease incidence

Foliar diseases were noted at 60, 75, and 90 days after sowing, and tuber diseases were assessed after harvesting on a 0-9 scale, with 0 indicating no disease and 9 indicating maximum disease.

Early blight

The scale for early blight disease was scored from 0 to 5 using the method described by Chaerani *et al.* (2007). The disease scales were converted to a percentage of the EB index (PEBI) for each plant using the following formula.

$$\text{PEBI} = \frac{\text{Sum of all ratings}}{\text{Number of leaves sampled} \times \text{maximum disease scale}} \times 100$$

Late blight

Disease scoring was done on a 1-9 scale (Jayaraj *et al.*, 2008). PDI (Per cent Disease Index) data were recorded from the day of first disease appearance until harvest at weekly intervals.

Bacterial wilt (%)

The number of plants showing symptoms of bacterial wilt was counted and recorded. The percentage was calculated by using the following formula.

$$\text{Affected plants per plot} = \frac{\text{Number of plants showing the symptom}}{\text{Total number of plants in the plot}} \times 100$$

Quality attributes

Specific gravity (kg/cm³)

The specific gravity of potato tubers was determined using the procedure described by Das *et al.* (2021). Specific gravity was calculated using the formula.

$$\text{Weight in air Specific gravity} = \frac{\text{Weight in air}}{(\text{Weight in air} - \text{Weight in water})}$$

Chlorophyll content (SPAD value)

Chlorophyll content at 45 days after planting was measured using a SPAD-502 and expressed in SPAD units (Wadas and Dziugiel, 2020).

Total soluble solids (°Brix)

The juice from fresh potato tubers was obtained from sliced tubers, and total soluble solids were recorded with a digital refractometer (0-30). The average was calculated from five tubers and expressed in (°Brix).

Starch content (%)

The starch content in potato was estimated according to the protocol outlined by Das *et al.* (2021).

Storage behavior

Potato tuber samples from each treatment, at approximately 1.0 kilogram per treatment, were taken, and observations were recorded for 90 days of storage at 30-day intervals.

Physiological loss in weight [PLW (%)]

The percentage reduction in the physiological loss of weight was computed using the following formula.

$$\text{PLW (\%)} = \frac{\text{Initial weight of tubers} - \text{Final weight of tubers}}{\text{Initial weight of tubers}} \times 100$$

Sprouted tubers (%)

The percentage of sprouted tubers was calculated by using the following formula.

$$\text{Sprouted tubers (\%)} = \frac{\text{Number of sprouted tubers}}{\text{Total number of tubers}} \times 100$$

Rotten tubers (%)

The percentage of rotten tubers was calculated by using the following formula.

$$\text{Rotten tubers (\%)} = \frac{\text{Number of rotten tubers}}{\text{Total number of bulb tubers}} \times 100$$

Statistical analysis of data interpretation of data

The experimental data obtained were subjected to statistical analysis using Fisher's method of analysis of variance, as outlined by Gomez and Gomez (1984). The critical difference (CD) values were given in the table at the 5 percent significance level. A simple ANOVA was used for statistical analysis on the online OPSTAT website. The results were compared at the 5 percent significance level.

FINDINGS AND DISCUSSION

Biotic Resistance

Effect of bio-stimulants on pest infestation and disease incidence was significant in potato during both *Rabi* and *Kharif* seasons (Table 1).

Aphids

During both *Rabi* (3.05) and *Kharif* (2.29) seasons, at 60 DAP, aphid count was significantly lowest with whole tubers RDF + Humic acid at 2 ml L⁻¹. Whereas, the highest aphid population per plant of 4.58 and 3.37 was recorded in the control during *Rabi* and *Kharif*, respectively.

Cutworm

The treatment consisting of whole tubers + RDF + Humic acid at 2 ml L⁻¹ had the lowest cutworm count of 2.04 and 1.45 at 60 DAP during *Rabi* and *Kharif*, respectively. At the same time, the control had the highest cutworm population per plant, 3.33 and 2.32, respectively, during the *Rabi* and *Kharif* seasons.

Potato Tuber Moth [PTM (%)]

After 30 days of storage, there was no PTM infestation among all the treatments. At 60 days after storage, significant PTM infestation was found in both seasons. The PTM infestation was significantly lowest in the treatment comprising whole tubers + RDF + Humic acid at 2 ml L⁻¹ (11.82% and 8.05%, respectively). Whereas, the highest PTM infestation (15.46% and 10.11%) was observed in the control during the *Rabi* and *Kharif* seasons, respectively.

In both seasons, the lowest infestation of potato tuber moth was observed with whole tubers + RDF + Humic acid at 2 ml L⁻¹ (22.71 and 20.21 %, respectively). Whereas, the maximum PTM infestation (31.05 and 24.03 %) was noted in the control during the *Rabi* and *Kharif* seasons, respectively.

Bio-stimulants can enhance nutrient uptake and improve overall plant nutrition, making plants less susceptible to diseases and pests. A well-nourished potato plant is better equipped to withstand biotic stress (Farouk *et al.*, 2013). Moreover, bio-stimulants can influence the synthesis and metabolism of plant hormones such as auxins, cytokinins, gibberellins, and jasmonates, which play crucial roles in defense mechanisms against pests and diseases (Patterson and Alykhin, 2014; Ren *et al.*, 2021). The study was in line with the study by Mulugeta *et al.* (2018) on potato.

Disease incidence

Early Blight (%)

During the *Rabi* season, no cases of early blight were observed. During the *Kharif* season, lower early blight incidence was observed with whole tubers + RDF + Humic acid at 2 ml L⁻¹ (6.99 %). While the control recorded a higher early blight incidence of 8.17%.

Late blight (%)

The treatment comprising whole tubers + RDF + Humic acid at 2 ml L⁻¹ showed the least incidence of late blight at 7.83% and 9.87% during *Rabi* and *Kharif*, respectively. Whereas, the highest percentage of late blight occurrence was observed in the control (10.38% and 11.97% during *Rabi* and *Kharif* seasons, respectively).

Bacterial wilt (%)

Bacterial wilt differed significantly among treatments during both *Rabi* and *Kharif* seasons, with the least bacterial wilt observed with whole tubers + RDF + Humic acid at 2 ml L⁻¹ during *Rabi* and *Kharif* (1.95 and 1.49 %, respectively). The highest bacterial wilt incidence of 2.97% and 2.34% was found in the control.

All the bio-stimulant treatments improved biotic resistance in potatoes, significantly reduced pest infestations and disease incidence. The most effective treatment was whole tubers + RDF + Humic acid at 2 ml L⁻¹. This treatment performed *on par* with cut tubers + RDF + Humic acid at 2 ml L⁻¹, as well as whole tubers + RDF + Seaweed extract at 2 ml L⁻¹, which ranked second and third, respectively.

Bio-stimulants enhance plant immunity and stimulate innate defense mechanisms, including the production of defense-related proteins, phytoalexins, and pathogenesis-related (PR) proteins. These substances inhibited the growth and development of pathogens, thus reducing disease severity in potato crops (Rouphael *et al.*, 2017). Bio-stimulants can trigger systemic acquired resistance (SAR) or induced systemic resistance (ISR) in plants. ISR involves the activation of defense mechanisms in response to signals from beneficial microbes or bio-stimulants, leading to enhanced resistance against a wide range of pathogens (Choudhary *et al.*, 2007).

Bio-stimulants suppress disease through induced systemic resistance (ISR) and other mechanisms. Larkin (2008) showed that using compost tea with *Bacillus spp.*, *Streptomyces griseoviridis*, *T. harzianum*, humic acids, seaweed, and yeast extracts reduced stem canker, black scurf, and common scab by 18-33%. *T. harzianum* strain T39 also decreased downy mildew symptoms by triggering local and systemic resistance (Cappelletti *et al.*, 2017).

Table: 1. Influence of Bio-stimulants on pest infestation and disease incidence in potato (*Solanum tuberosum* L.)

Treatment s	Rabi					Kharif								
	Aphid s	Cutwor m	6o	9o	Early Bligh t (%)	Late Bligh t (%)	Bacteri al Wilt (%)	Aphid s	Cutwor m	6o	9o	Early Bligh t (%)	Late Bligh t (%)	Bacteri al Wilt (%)
			DAS PTM (%)	DAS PTM (%)						DAS PTM (%)	DAS PTM (%)			
T ₁	4.58 ^a	3.33 ^a	15.46 ^a	31.05 ^a	NI	10.38 ^a	2.97 ^a	3.37 ^a	2.32 ^a	10.11 ^a	24.03 ^a	8.17 ^a	11.97 ^a	2.34 ^a
T ₂	3.05 ^c	2.04 ^d	11.82 ^c	22.71 ^d	NI	7.83 ^c	1.95 ^f	2.29 ^d	1.45 ^d	8.05 ^c	20.21 ^b	6.99 ^b	9.87 ^c	1.49 ^g
T ₃	3.54 ^b	2.56 ^{bc}	14.40 ^a	27.60 ^{ab}	NI	8.80 ^b	2.32 ^{cd}	3.05 ^b	1.95 ^b	9.08 ^b	21.59 ^b	7.67 ^{ab}	11.03 ^{ab}	2.01 ^{cde}
T ₄	3.50 ^b	2.47 ^{bc}	14.20 ^a	26.71 ^{bc}	NI	8.23 ^{bc}	2.20 ^{de}	2.96 ^b	1.91 ^b	8.97 ^b	21.30 ^b	7.45 ^{ab}	10.54 ^{bc}	1.93 ^{ef}
T ₅	3.66 ^b	2.59 ^b	14.56 ^a	30.00 ^{ab}	NI	8.74 ^{bc}	2.52 ^b	3.14 ^{ab}	2.01 ^b	9.19 ^b	21.66 ^b	8.03 ^a	11.07 ^{ab}	2.14 ^{bc}
T ₆	3.21 ^c	2.36 ^c	13.41 ^b	24.42 ^{cd}	NI	8.25 ^{bc}	2.04 ^{ef}	2.64 ^c	1.65 ^c	8.63 ^b	20.80 ^b	7.16 ^b	10.50 ^{bc}	1.85 ^f

T ₇	3.64 ^b	2.60 ^b	14.55 ^a _b	29.54 ^a _b	NI	8.78 ^{bc}	2.48 ^{bc}	3.12 ^{ab}	1.98 ^b	9.12 ^b _b	21.69	7.62 ^{ab}	11.10 ^{ab}	2.10 ^{bcd}
T ₈	3.57 ^b	2.49 ^{bc}	14.21 ^a _b	29.01 ^{ab}	NI	8.66 ^b _c	2.32 ^{cd}	3.02 ^b	1.93 ^b	9.01 ^b _b	21.43	7.53 ^{ab} _c	10.98 ^{ab}	1.98 ^{def}
T ₉	3.70 ^b	2.65 ^b	14.65 ^a _b	30.43 ^{ab}	NI	8.89 ^b	2.60 ^b	3.16 ^{ab}	2.01 ^b	9.21 ^b _b	21.80	7.75 ^{ab}	11.18 ^{ab}	2.18 ^b
S Em±	0.10	0.07	0.41	1.20	-	0.28	0.06	0.08	0.05	0.26	0.64	0.23	0.35	0.05
CD at 5%	0.29	0.20	1.24	3.58	-	0.84	0.17	0.24	0.15	0.79	1.91	0.70	1.04	0.14

Note: DAS- Days After Storage, PTM- Potato Tuber Moth, NI- No Incidence

Quality attributes

The quality attributes as influenced by bio-stimulants during both *Rabi* and *Kharif* seasons are presented in Table 2 below.

Chlorophyll content

Non-significant difference was observed in respect of chlorophyll content (SPAD value) with the application of bio-stimulants during both *Rabi* and *Kharif* seasons.

Specific gravity (kg/cm³)

The results revealed that the specific gravity of potato tubers was not statistically significant.

Total soluble solids (°Brix)

Among the treatments, significantly higher TSS was noticed during both *Rabi* and *Kharif* seasons (5.41 and 5.43 °Brix, respectively). While the lowest TSS was recorded in control (4.66 and 4.78 °Brix, respectively) during both seasons.

Starch content (%)

Among the treatments, the maximum starch content was significantly higher with whole tubers + RDF + Humic acid at 2 ml L⁻¹ (19.11 and 19.20 %, respectively). While, control recorded the lowest starch content of 15.54% and 15.75%, respectively, during the *Rabi* and *Kharif* seasons.

Bio-stimulants may have variable effects on potato specific gravity; the limited response of the Kufri Himalini variety may be due to stable genetic traits, optimal growing conditions, and nutrient levels (Canellas *et al.*, 2015).

Bio-stimulants like humic acid and seaweed extract can enhance potato quality by increasing Total Soluble Solids (TSS) and starch content, potentially improving taste and flavor (Selim *et al.*, 2010). Further, they positively influence starch content by enhancing the activity of enzymes involved in starch biosynthesis, thereby improving the texture and cooking quality of potatoes (Alenazi *et al.*, 2016; Alkharpotly *et al.*, 2018).

Table: 2. Effect of Bio-stimulants on quality attributes in potato (*Solanum tuberosum* L.)

Treatments	<i>Rabi</i>				<i>Kharif</i>			
	Chlorophyll content (SPAD units)	Specific gravity (kg/cm ³)	TSS (° Brix)	Starch Content (%)	Chlorophyll content (SPAD units)	Specific gravity (kg/cm ³)	TSS (° Brix)	Starch Content (%)
T ₁	41.27	1.06	4.66 ^b	15.54 ^e	41.63	1.06	4.78 ^b	15.75 ^d
T ₂	45.07	1.07	5.41 ^a	19.11 ^a	45.90	1.07	5.43 ^a	19.20 ^a
T ₃	42.50	1.06	4.82 ^b	16.51 ^{cde}	43.60	1.07	4.85 ^b	16.65 ^{cd}
T ₄	44.10	1.06	4.81 ^b	17.49 ^{bc}	45.23	1.07	4.90 ^b	17.73 ^{bc}
T ₅	42.30	1.06	4.74 ^b	15.96 ^e	43.23	1.06	4.83 ^b	16.12 ^d
T ₆	44.60	1.07	4.94 ^b	18.02 ^{ab}	45.50	1.07	5.04 ^b	18.22 ^{ab}
T ₇	41.83	1.06	4.63 ^b	16.29 ^{de}	42.90	1.07	4.76 ^b	16.54 ^{cd}
T ₈	42.70	1.06	4.78 ^b	17.26 ^{bcd}	43.73	1.07	4.84 ^b	17.56 ^{bc}
T ₉	42.00	1.06	4.71 ^b	15.72 ^e	43.07	1.06	4.79 ^b	16.09 ^d
S Em±	1.01	0.03	0.15	0.37	1.08	0.03	0.13	0.38
CD at 5%	NS	NS	0.44	1.10	NS	NS	0.40	1.15

Storage behavior

The data on storage behavior influenced by bio-stimulant application are presented in Table 3.

Physiological loss in weight [PLW (%)]

At 30, 60 and 90 days of storage, minimum PLW was recorded with whole tubers + RDF + Humic acid at 2 ml L⁻¹ (1.71, 6.32, 14.32%) during *Rabi* season, respectively, and 1.43, 5.49, 14.64 %, during *Kharif* season, respectively. Whereas, control registered maximum physiological weight loss of (2.90, 7.37, 17.08%, respectively) and 2.41, 6.54, 17.40 %, respectively) during *Rabi* and *Kharif* seasons.

Sprouting (%)

No sprouting of potato tubers was observed at 30 days after storage with any of the applied bio-stimulants during both *Rabi* and *Kharif* seasons. Whereas at two months of storage, during the *Rabi* and *Kharif* seasons, the lowest sprouting was observed with whole tubers + RDF + Humic acid at 2 ml L⁻¹ (35.54 and 34.01 %, respectively). The control recorded the maximum sprouting percentages of 42.02% and 39.59%, respectively.

100% sprouting of potato tubers was observed at 90 days after storage, with all applied bio-stimulants, under room temperature conditions during both *Rabi* and *Kharif* seasons.

Tuber rot (%)

The findings showed that no tuber rot was noticed throughout the *Rabi* and *Kharif* seasons at one month of storage. At two months of storage, the treatment comprising whole tubers + RDF + Humic acid at 2 ml L⁻¹ had the lowest percentage of tuber rot (5.15% and 2.00%, respectively). Control had the highest percentage of tubers rotting (7.89% and 2.39%, respectively) during the *Rabi* and *Kharif* seasons.

At three months of storage, tuber rotting during *the Rabi and Kharif seasons was lowest (14.04% and 8.48%, respectively)* with whole tubers + RDF + Humic acid at 2 ml L⁻¹. At the same time, control had the highest percentage of tuber rot (17.78% and 11.23%, respectively) at three months of storage under ambient conditions.

Bio-stimulants can have various effects on the storage behavior of potato and other tuber crops, including influencing physiological weight loss, sprouting, and tuber rot (Rouphael and Colla, 2020).

Bio-stimulants reduce physiological weight loss by enhancing tuber structure, moisture retention, and hormonal balance, delaying aging and promoting dormancy (Ertani *et al.*, 2017). They strengthen plant defenses, increase antimicrobial production, and lower susceptibility to rot while preserving tissue integrity, reducing respiration rates, and maintaining water balance in stored vegetables (Rouphael *et al.*, 2010)

Table: 3. Influence of Bio-stimulants on storage behavior in potato (*Solanum tuberosum L.*)

Treatments	<i>Rabi</i>						<i>Kharif</i>											
	PLW (%)			Sprouting (%)			Tuber rot (%)			PLW (%)			Sprouting (%)			Tuber rot (%)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T ₁	2.90 ^a	7.37 ^a	17.08 ^a	0.0 ^o	42.02 ^a	100.0 ^o	0.0 ^o	7.89 ^a	17.78 ^a	2.41 ^a	6.54 ^a	17.40 ^a	0.0 ^o	39.59 ^a	100.0 ^o	0.0 ^o	2.39 ^a	11.23 ^a
T ₂	1.71 ^f	6.32 ^d	14.32 ^c	0.0 ^o	35.54 ^d	100.0 ^o	0.0 ^o	5.15 ^d	14.04 ^c	1.43 ^c	5.49 ^d	14.64 ^c	0.0 ^o	34.01 ^b	100.0 ^o	0.0 ^o	2.00 ^b	8.48 ^c
T ₃	2.46 ^c	6.71 ^{bc}	16.18 ^a	0.0 ^o	40.97 ^{ab}	100.0 ^o	0.0 ^o	7.43 ^a	15.18 ^b	1.96 ^b	5.88 ^{bc}	16.50 ^a	0.0 ^o	39.22 ^a	100.0 ^o	0.0 ^o	2.35 ^a	10.45 ^a
T ₄	2.09 ^e	6.44 ^d	15.62 ^a	0.0 ^o	40.60 ^a	100.0 ^o	0.0 ^o	6.96 ^b	14.62 ^b	1.59 ^c	5.61 ^d	15.94 ^a	0.0 ^o	39.20 ^a	100.0 ^o	0.0 ^o	2.35 ^a	10.28 ^a
T ₅	2.57 ^b	7.01 ^{ab}	16.56 ^a	0.0 ^o	40.96 ^a	100.0 ^o	0.0 ^o	7.23 ^a	15.31 ^b	2.03 ^b	5.84 ^{bc}	16.88 ^a	0.0 ^o	39.27 ^a	100.0 ^o	0.0 ^o	2.41 ^a	10.56 ^a

T ₆	1.93 ^e	6.42 ^d	15.34 ^{bc}	0.0 _o	36.68 ^b	100.0 _o	0.0 _o	6.07 ^c	14.39 ^c	1.54 ^c	5.59 ^d	15.66 ^{bc}	0.0 _o	35.57 ^a	100.0 _o	0.0 _o	2.16 ^b	9.41 ^{bc}
T ₇	2.48 ^c	6.94 ^b	16.29 ^a	0.0 _o	40.98 ^a	100.0 _o	0.0 _o	7.24 ^a	15.36 ^b	1.98 ^b	6.10 ^{bc}	16.60 ^a	0.0 _o	39.31 ^a	100.0 _o	0.0 _o	2.39 ^a	10.58 ^a
T ₈	2.29 ^d	6.61 ^c	15.74 ^{ab}	0.0 _o	40.78 ^{ab}	100.0 _o	0.0 _o	7.11 ^b	14.82 ^b	1.96 ^b	5.78 ^{cd}	16.06 ^a	0.0 _o	39.25 ^a	100.0 _o	0.0 _o	2.36 ^a	10.45 ^a
T ₉	2.66 ^b	7.08 ^a	16.61 ^a	0.0 _o	41.03 ^{ab}	100.0 _o	0.0 _o	7.34 ^a	15.45 ^b	2.11 ^b	6.25 ^{ab}	16.93 ^{ab}	0.0 _o	39.28 ^a	100.0 _o	0.0 _o	2.46 ^a	10.67 ^a
S Em±	0.05	0.13	0.46	0.0 _o	1.30	0.00	0.0 _o	0.22	0.54	0.05	0.13	0.48	0.0 _o	1.23	0.00	0.0 _o	0.06	0.47
CD at 5%	0.16	0.40	1.39	0.0 _o	3.89	0.00	0.0 _o	0.66	1.63	0.15	0.40	1.43	0.0 _o	3.68	0.00	0.0 _o	0.17	1.42

Note: DAS- Days After Storage

CONCLUSION

The findings from this study underscore the efficacy of bio-stimulants in enhancing the biotic resistance, quality, and storage behavior of potatoes. The use of humic acid, amino acids, seaweed extracts, and microbial consortia proved to be a viable alternative to chemical fertilizers and pesticides. The results indicated that whole tubers + RDF + soil application of 2 mL L⁻¹ humic acid effectively boosted the plants' natural defenses, resulting in reduced pest populations and disease incidence, enhanced quality attributes, and improved storage performance. Consequently, bio-stimulants offer a sustainable approach to potato cultivation, potentially leading to improved crop management practices and higher-quality yields.

Authors' Contributions

Mohammad Nasim Ayobi, Mallikarjuna Gowda, A. P., and Manjunath, B., conceptualized the research, conducted the literature review, and were responsible for writing and editing the original manuscript. Rahmat Gul Hassanzai provided technical guidance, critical review, and suggestions for manuscript improvement.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Data Availability Statement

Data is available upon request from the corresponding author, subject to the approval of the relevant ethics committee.

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