PLANT SCIENCE TODAY
Vol 13(sp1): 1-8
https://doi.org/10.14719/pst.10297

eISSN 2348-1900

RESEARCH ARTICLE

Evaluation of methanotroph-derived protein hydrolysate biostimulant on grapevine yield and quality in diverse agroecological zones of India

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Received: 26 June 2025; Accepted: 08 December 2025; Available online: Version 1.0: 05 March 2026

Cite this article: Somkuwar RG, Kakade PB, Mahalle SP, Chavadi B, Venkatesh S, Sarma RK, Gangigere JP. Evaluation of methanotroph- derived protein hydrolysate biostimulant on grapevine yield and quality in diverse agroecological zones of India. Plant Science Today. 2026; 13(sp1): 1-8. https://doi.org/10.14719/pst.10297

Abstract

Grapes (*Vitis vinifera* L.) is an important fruit crop in tropical and subtropical regions. However, its production faces challenges from stresses like unseasonal rains and poor soil quality, particularly affecting table varieties like Thompson Seedless, its clone. Protein hydrolysate (PH) based biostimulants offer a promising solution by improving plant metabolism, increasing stress resilience and enhancing both berry yield and quality. This study evaluated the effect of a methanotroph derived PH biostimulant across diverse agroecological regionsin India, aiming to assess their impact on grapevine yield, berry quality and shelf life at varying concentrations. The validation was conducted in Karnataka, Telangana State and Maharashtra during the 2022–2023 growing season. The field experiment employed a Randomized Block Design (RBD) with 8 treatments, including 6 levels of PH, a commercial control and an untreated control. Protein hydrolysate was applied at 4 key developmental stages and results showed that the 5 mL/L treatment (T_7) consistently outperformed others, enhanced berry length (35.93, 33.00 and 27.03 mm) and diameter (15.20, 20.57 and 23.03 mm) improved Total Soluble Solids (TSS) (18.43, 18.20 and 18.20 °Brix) and extended shelf life proving optimal dose for enhancing yield and quality in Manik Chaman, Bangalore Blue and Thompson Seedless respectively. T_7 treatment also performed better in 3 different locations with ~32–48 % increases in yield and improved shelf life. The study highlights the significant benefits of methanotroph derived PH bio stimulant in improving grapevine productivity and fruit quality.

Keywords: berry quality enhancement; grapevine yield improvement; methanotroph-derived biostimulant; protein hydrolysate; shelf-life extension

Introduction

Grapes (*Vitis vinifera* L.) is an important commercial fruit crop cultivated in different tropical and subtropical regions. Although the grapevine originates from temperate regions, it has adapted to tropical climates where vines do not undergo dormancy. Major grape-producing regions in India include Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh and Mizoram, benefiting from the adaptability of grape genotypes to diverse agroecological zones. In 2024, grape production reached 3.896 million metric tonnes from an area of 17690 ha (1). During the fiscal year 2023–24, the country exported 343982.34 metric tonnes, valued at 417.07 million USD (2). Grape berries are edible foods with numerous nutritional and medicinal properties. Owing to high quality and better pigmentation, seedless grape varieties are gaining popularity off late. Thompson Seedless and its clones like Tas-A-Ganesh, Manik Chaman and Sonaka are commercially accepted table grape varieties both for the domestic as well as international markets. Consumer preferences for table grapes include higher bunch size, superior berry shape, better skin color, skin thickness and flesh hardness. In addition, enhanced flavor, aroma and sugar: acid ratio is consumer preferred attributes in grapes (3). Seasonal variations in environmental factors such as biotic and abiotic stresses are hampering grape yield and quality. Further, unseasonal rains, soil salinity, drought and poor-quality irrigation water are some of the other challenges in the production of grapevine cultivation (4). In recent years, innovative inputs like biostimulants have been widely used to horticultural crops as they have plant growth-promoting effects. Biostimulants to boost metabolic activity and maintain optimal growth during vegetative and reproductive stages in grapevine is considered pre-requisite to maintain yield attributes (3–5). It has been reported that foliar application of biostimulants improved stress tolerance, enhanced yield and increased berries pigmentation. Among the different classes of biostimulants, PH based biostimulants are composed of free amino acids, oligopeptides and polypeptides, produced through chemical, enzymatic or combined chemical-enzymatic hydrolysis of plant residues, animal tissues or other protein rich sources (6). While PHs help activate plant defence mechanisms under stressful conditions, they are known to enhance growth and yield in non-stressed environments. They improve leaf gas exchange by promoting pigment synthesis and protecting the plant, while also boosting water-use efficiency (7, 8). Additionally, PHs exhibit hormone-like activity, modulating carbon and nitrogen metabolism and enhancing antioxidant properties during stress. Protein hydrolysate can be applied via seed priming, soil drenching or foliar spraying (9, 10). Their application promotes plant growth and development (7), especially by altering root architecture through increased root length, branching and surface area (11). However, high doses of animal-based PHs can cause phytotoxicity and inhibit plant growth (12). Importantly, exogenous PH applications support root health, balancing the carbon-to-nitrogen ratio, which is essential for plant vitality. Despite the promising benefits of PH biostimulants, limited research has explored their impact on table grape varieties across India's diverse agroecological zones. Thus, a research trial was conducted to understand the performance of String's methanotroph-derived PH biostimulant, Grepa® in improving grapevine yield, berry quality and shelf-life across diverse agroecological regions. The main objective is to determine the optimal application dose and stage for maximizing these benefits in Indian viticulture.

Materials and Methods

Experimental conditions

The experimental trial was carried out across three different Agroecological Regions (AER) in India during the 2022–2023 growing season. The selected locations included Bangalore (AER-08) in Karnataka, Hyderabad (AER-07) in Telangana State and Rahata (AER-06) in Maharashtra. The most popular grape varieties grown in each of these locations were selected to understand the impact of Grepa® a methanotroph-derived PH. The varieties selected for testing are, Bangalore Blue for Bangalore, Manik Chaman for Hyderabad and Thompson Seedless for Maharashtra. In Bangalore, 6-year-old Bangalore Blue vines grafted onto Dogridge rootstocks were selected. These vines were trained on a bower system, with a spacing of 10 feet between rows and 6 feet between vines, allowing for the accommodation of 726 vines per acre. In contrast, the vines in Hyderabad and Maharashtra were trained on Y-trellis systems or lyre vine training system with spacing of 9 × 5 feet, allowing for 968 vines per acre.

The experiment followed a RBD consisting of eight treatments and three replications. Foundation pruning was performed in April 2022, followed by forward pruning in October 2022. The standard package of agronomic practices was applied during the experiment. The 8 treatments included a control that received a water spray, a commercial control PH biostimulant (tested at a dose of 2.5 mL/L) and six levels of String's PH (dose ranging from 0.5, 1.0, 2.0, 2.5, 5.0 and 7.5 mL/L). String's PH is commercially known as Grepa®. Grepa®, a PH based biostimulant commercialized by String Bio, India, is a unique mixture containing amino acids and peptides manufactured using an IP protected fermentation process (PCT application WO2021240470A1; Hydrolysate based biostimulant compositions derived from methanotroph, methods and applications thereof).

The spray volume ranged from 250 to 400 L/acre depending on the canopy size. The foliar application of PH biostimulants was applied during different growth stages of crop growth. The details of the treatment and concentration are provided in Table 1. The final harvesting dates were March 27, 2023, in Hyderabad, April 1, 2023 in Bangalore and April 11, 2023 in Rahata.

Yield parameters

Grape bunches were harvested after attaining physiological maturity. Five bunches were harvested randomly from each vine and the average bunch weight was recorded and expressed in g. From each replication, 50 berries were removed from the bunch randomly and 50-berry weight was recorded and expressed in g. Number of berries per bunch were counted from the 5 bunches harvested. The number of bunches per vines were counted from selected 5 vines in each treatment and mean number of bunches per vine was recorded. Bunches were harvested after attaining physiological maturity (by assessing the TSS and sugar acid ratio). The yield was recorded at the time of harvest and expressed in kg per vine, tonnes per acre and tonnes per hectare.

Berry quality parameters

Ten berries were randomly selected from each replication for the measurements of berry diameter (mm) and berry length (mm) using vernier caliper and values were expressed in mm. After harvest of grape bunches, 10 berries were removed randomly and the juice was extracted. One drop of juice was then kept on the mirror of refractometer. The TSS was then expressed in °Brix. In addition, after harvest of fruits, the juice was extracted and analyzed for acidity (%), protein (mg/g), carbohydrate (mg/g), phenol (mg/g) and reducing sugars (mg/g) estimated as previously described (13, 14).

Physiological Loss in Weight (PLW)

Grape bunches harvested from each treatment were placed under regular storage conditions for 5 days to assess PLW. The initial weight of each bunch was recorded and after the 5-day period, the

Table 1. Treatments details and stage of String protein hydrolysate (Grepa®) biostimulant application

Treatment	Product	Dosage (mL/L)	Method and time of application
T_1	Control	--	
T_2	Commercial control	2.5 mL/L	Method of application: Foliar
T_3	String's protein hydrolysate	0.5 mL/L	
T_4	String's protein hydrolysate	1.0 mL/L	First application- At flower initiation (~45–50 days after pruning/50 % flowering)
T_5	String's protein hydrolysate	2.0 mL/L	
T_6	String's protein hydrolysate	2.5 mL/L	Second application- At berry set/fruit initiation (~60–65 days after fruit pruning)
T_7	String's protein hydrolysate	5.0 mL/L	
			Third application- At berry/ fruit development stage (~75–80 days after pruning)
T_8	String's protein hydrolysate	7.5 mL/L	Fourth application- At veraison stage (~95–100 days after fruit pruning/during 50 % veraison)

*String's protein hydrolysate's commercial name is Grepa®

final weight was measured.

Statistical analysis

Data collected during the experiment was subjected to statistical analysis using SAS Version 9.3 software. Tukey's test was employed to compare the means of different treatments for significant differences.

Results

Location: Hyderabad, Telangana state

Effect of String's PH on bunch and berry parameters of Manik Chaman

The data recorded on various bunch and berry parameters in Manik Chaman is presented in Table 2. The bunches per vine were maintained after forward pruning based on the purpose and the remaining bunches were removed at the time of flowering. Hence, the number of bunches per vine was non-significant. However, the average bunch weight varied significantly from 327.20 g to 411.33 g among the treatments. Treatment T_7 recorded highest average bunch weight (411.33 g) followed by T_8 (394.77 g) as compared to the lowest in control T_1 treatment (327.20 g). The number of berries per bunch was on par among different treatments. Fifty berry weight also varied significantly among the different treatments. The 50-berry weight ranged from 211.20–232.00 g among different treatments. The highest 50-berry weight was recorded in T_7 (232.00 g) followed by T_8 (226.43 g) as compared to the lowest in T_1 (211.20 g). Application of String's PH also resulted in increase in yield/vine, yield/acre and yield/ha. The treatment T_7 recorded highest yield/vine, yield/acre and yield/ha (20.63 kg/vine, 19.97 t/acre and 49.33 t/ha, respectively). The performance of T_7 treatment was at par with treatment T_8, while the untreated control T_1 recorded lowest yield of 15.60 kg/vine, 15.10 t/acre and 37.30 t/ha respectively, indicating the significance of String's PH in improving the grape yield.

Effect of String's PH on berry quality parameters of Manik Chaman

The data recorded on berry quality parameters is presented in Table 3. Among the different berry quality parameters, berry diameter is the most important parameter for round and oblong type of table grape varieties. The result of String's PH on berry diameter was positive. Berry diameter varied significantly among the different treatments. Berry diameter ranged from 12.77 mm to 15.20 mm. Highest berry diameter was recorded in T_7 (15.20 mm) followed by T_8 (14.83 mm) and T_6(14.60 mm) while minimum in T_2 (13.50 mm) as compared to the lowest in T_1(12.77 mm). Berry length is considered as an important quality parameter in elongated grapes. Berry length ranged from 29.17 mm to 35.93 mm among the different treatments. The highest berry length was recorded in T_7 (35.93 mm) followed by T_8 (34.00 mm) and T_6 (33.70 mm) while the lowest berry length was recorded in 31.50 mm (T_3), 30.00 mm (T_2) as compared to the lowest in control T_1 (29.17 mm). Significant differences were recorded for TSS among the different treatments. Highest TSS was recorded in T_4 (18.73 °Brix) followed by T_5 (18.27 °Brix), T_6 (18.60 °Brix) and T_7 (18.43 °Brix) while the minimum in T_3 (18.03 °Brix) as compared to 17.27 °Brix in commercial control and the lowest TSS in control T_1 (16.60 °Brix). The acidity ranged from 0.48–0.55 % in different treatments.

Effect of String's PH on fruit biochemicals of Manik Chaman

The data recorded on various fruit biochemicals are presented in Table 3. Significant differences were recorded for all the biochemicals studied. Among the various biochemicals, phenols ranged from 0.25 mg/g FW to 0.93 mg/g FW. The significantly higher phenol content was recorded in T_7 treatment (0.93 mg/g FW) followed by T_6 (0.60 mg/g FW) and T_6(0.60 mg/g FW) while the lowest concentration was estimated in T_3 and T_4 (0.25 mg/g FW) respectively. Tannin content ranged from 0.33 mg/g FW in $T_7$to 0.81 mg/g FW in T_3 treatment. Reducing sugar was in higher concentration in T_7 (219.87 mg/g FW) followed by 214.97 mg/g FW in T_8 and 225.37 mg/g FW in T_5 as compared to lowest

Table 2. Effect of String's PH on yield parameters of Manik Chaman in Hyderabad, India

Treatment	Bunches/ Vine	Av. bunch weight (g)	No. of berries/bunch	50 berry weight (g)	Yield/vine (kg)	Yield/ acre (t)	Yield/ ha (t)
T_1	47.67	327.20	145.33	211.20	15.60	15.10	37.30
T_2	48.23	340.80	145.67	212.87	16.43	15.93	39.35
T_3	48.60	369.50	150.13	218.10	17.93	17.37	42.90
T_4	49.03	382.40	147.33	220.27	18.70	18.13	44.78
T_5	49.23	391.37	148.23	223.43	19.27	18.63	46.02
T_6	49.57	393.03	148.47	225.10	19.47	18.87	46.61
T_7	50.13	411.33	146.57	232.00	20.63	19.97	49.33
T_8	51.27	394.77	149.80	226.43	20.20	19.60	48.41
S Em ±	1.34	39.70	1.20	2.95	2.00	1.95	4.77
CD at 5 %	-	12.96	-	9.02	0.65	0.63	1.56
Sig	NS	**	NS	**	**	**	**

Table 3. Effect of string's PH on quality and biochemical parameters of Manik Chaman in Hyderabad

Treatment	Berry diameter (mm)	Berry length (mm)	TSS (°Brix)	Acidity (%)	Phenol (mg/ g FW)	Tannin (mg/g FW)	Reducing sugar (mg/g FW)	Carbohydrates (mg/g FW)	Protein (mg/g FW)
T_1	12.77	29.17	16.60	0.48	0.57	0.72	159.43	26.48	1.48
T_2	13.50	30.00	17.27	0.52	0.54	0.69	214.20	27.98	1.50
T_3	13.73	31.50	18.03	0.55	0.25	0.81	212.53	21.98	1.73
T_4	14.03	31.67	18.73	0.49	0.25	0.31	186.63	34.01	1.53
T_5	14.20	32.00	18.60	0.50	0.52	0.35	225.37	16.14	1.57
T_6	14.60	33.70	18.23	0.50	0.60	0.34	206.70	30.99	1.66
T_7	15.20	35.93	18.43	0.50	0.93	0.33	219.87	28.80	1.93
T_8	14.83	34.00	18.27	0.49	0.27	0.36	214.97	22.30	1.60
S Em ±	0.27	0.88	0.17	0.01	0.12	0.04	5.39	1.61	0.01
CD at 5 %	0.83	2.70	0.51	0.03	0.35	0.14	16.50	4.95	0.05
Sig	**	**	**	*	*	**	**	**	**

concentration in T_1 (159.43 mg/g FW). The treatment T_4 recorded the highest concentration of carbohydrate (34.01 mg/g FW) as compared to the lowest in T_1 (26.48 mg/g FW). The same trend was also recorded for protein content among the different treatments. With the increase in String's PH dose, there was increase in fruit biochemicals with highest concentration in T_7 while lowest in T_1 (control).

Location: Bangalore, Karnataka

Effect of String's PH on bunch and berry parameters of Bangalore Blue

The data recorded in Bangalore Blue variety at Bangalore on various bunch and yield parameters is presented in Table 4. The bunches per vine varied significantly among the different String's PH treatments. Highest number of bunches/vines was observed in T_7 (160) followed by T_8 (157.8) with the lowest number of bunches in T_1 (130.1). The bunch retention concept in case of juice variety is not followed as is being followed in case of table grapes. The application of String's PH at different berry development stages resulted in significant changes in average bunch weight.

Average bunch weight varied significantly among the different concentrations of String's PH over the untreated control. At harvest, average bunch weight was highest in T_7 (137.59 g) followed by T_8 (133 g) over the control treatment T_1 (113 g). There was a significant difference in number of berries per bunch and it ranged between 50.07–55.07 in different treatments. The treatment T_8 recorded highest number of berries per bunch (55.07) and was on par with treatment T_6 and T_7 with 54.13 and 54.53 berries per bunch respectively. Lowest number of 50.07 berries per bunch was observed in untreated control (T_1). In addition to the berry number, the weight of individual berry contributes for the bunch weight. In the present study, 50-berry weight varied significantly among the different treatments. The treatment T_7 recorded 184.37 g while it was lowest in untreated control (T_1) with 159.53 g. Application of String's PH also resulted in increase in yield/vine, yield/acre and yield/ha. The treatment T_7 recorded highest yield/vine, yield/acre and yield/ha (11.67 kg/vine, 8.47 t/acre and 20.92 t/ha respectively). The performance of T_7 treatment was at par with treatment T_8, while the untreated control T_1 recorded lowest yield of 8.53 kg/vine, 6.17 t/acre and 15.24 t/ha respectively, indicating the significance of String's PH in improving the grape yield.

Effect of String's PH on berry quality parameters of Bangalore Blue

The grape quality mainly consists of berry length, berry diameter, TSS and acidity. The data recorded on grape berry quality is presented in Table 5. Berry diameter varied significantly among the different treatments. The treatment T_7 recorded highest berry diameter (20.57 mm) which was at par with T_8 (19.53 mm) and T_5 (19.17 mm) whereas treatment showed lowest berry diameter in untreated control T_1 (16.80 mm). Berry length varied significantly among the different concentrations of String's PH over the untreated control. At harvest, berry length was higher in T_7 (33.00 mm) followed by treatment T_8 (30.00 mm) while minimum was in T_1 control (27.67 mm). The differences for TSS among the different treatments were significant. TSS content was improved in all treatments studied. The treatment T_5 recorded maximum TSS (18.63 °Brix) which was at par with T_7 (18.20 °Brix). Among all the treatments studied, the lowest TSS was recorded in control treatment T_1 (16.70 °Brix). Maximum acidity was recorded in T_5 (0.57 %) followed by T_7 and T_8 (0.56 % in both the cases). However, the acidity in grape berries was within the acceptable limit in all the treatments.

Effect of String's PH on biochemical parameters

The data recorded on phenol, tannin, reducing sugar, carbohydrate and protein are presented in Table 5. Phenol content was relatively higher in T_1 (0.92 mg/g FW) while it was lowest in T_5 and T_3 (0.70 mg/g FW) treatment. The treatment T_5 recorded lowest tannin (0.84 mg/g FW) while it was highest in T_1 treatment (1.23 mg/g FW). Reducing sugar varied significantly among the different treatments. The treatment T_7 recorded

Table 4. Effect of String's PH on yield parameters of Bangalore Blue in Karnataka

Treatment	Bunches/vine	Av. bunch weight (g)	No. of berries per bunch	50 berry weight (g)	Yield/ vine (kg)	Yield/ acre (t)	Yield/ ha (t)
T_1	130.1	113.0	50.07	159.53	8.53	6.17	15.24
T_2	132.1	123.1	51.23	167.40	9.30	6.73	16.62
T_3	139.3	120.5	52.33	170.63	9.77	7.10	17.54
T_4	149.8	121.2	53.47	172.77	10.07	7.30	18.03
T_5	148.8	127.4	53.97	175.53	10.37	7.53	18.60
T_6	149.9	126.2	54.13	178.13	10.77	7.83	19.34
T_7	160.0	137.5	54.53	184.37	11.67	8.47	20.92
T_8	157.8	133.0	55.07	183.10	11.03	8.00	19.76
S Em ±	3.8	3.9	0.59	5.97	0.26	0.19	0.45
CD at 5 %	11.6	11.8	1.81	1.95	0.80	0.58	1.40
Sig	**	**	**	**	**	**	**

Table 5. Effect of String's PH on quality and biochemical parameters of Bangalore Blue in Karnataka

Treatment	Berry diameter (mm)	Berry length (mm)	TSS (°Brix)	Acidity (%)	Phenol (mg/g FW)	Tannin (mg/g FW)	Reducing sugar (mg/g FW)	Carbohydrates (mg/g FW)	Protein (mg/g FW)
T_1	16.80	27.67	16.70	0.50	0.92	1.23	184.08	13.58	2.97
T_2	17.57	28.00	16.80	0.51	0.83	1.13	189.67	23.15	2.65
T_3	18.23	28.33	16.87	0.52	0.70	0.84	207.17	29.85	2.90
T_4	18.67	28.67	17.00	0.53	0.66	0.86	188.33	13.93	2.79
T_5	19.17	29.33	18.63	0.57	0.70	1.00	183.25	12.40	2.46
T_6	19.10	30.33	17.33	0.54	0.71	0.93	185.42	11.87	3.01
T_7	20.57	33.00	18.20	0.56	0.83	1.08	214.25	16.93	2.75
T_8	19.53	30.00	17.40	0.56	0.76	0.90	156.58	17.79	2.95
S Em ±	0.57	0.34	0.38	0.009	0.006	0.06	6.76	2.12	0.03
CD at 5 %	1.75	1.03	1.16	0.027	0.019	0.18	20.70	6.50	0.09
Sig	*	**	*	**	**	**	**	**	**

significantly higher reducing sugar (214.25 mg/g FW) which was at par with T_3 (207.17 mg/g FW) whereas the treatment T_1 showed lowest reducing sugar (184.08 mg/g FW). The significantly higher carbohydrate was recorded in treatment T_3 (29.85 mg/g FW) while minimum carbohydrate (11.87 mg/g FW) was observed in treatment T_6. Protein was relatively higher in T_6 (3.01 mg/g FW) while it was lowest in T_5 (2.46 mg/g FW) treatment.

Location: Rahata, Maharashtra

Effect of String's PH on yield parameters of Thompson Seedless

The data recorded on number of bunches/vines, average bunch weight (g), 50-berry weight and yield per vine, yield per acre and yield per hectare in Thompson Seedless variety are presented in Table 6. The observations were recorded at harvesting stage. It was observed that with the application of String's PH, there was no significant effect on number of bunches per vine and number of berries per bunch. This was mainly due to the fact that the fruit bud differentiation was already been completed during the period of 40 to 70 days after the foundation pruning. In addition, considering the quality yield for export purpose, bunch thinning is also done immediately after berry set.

Average bunch weight varied significantly among the different concentrations of String's PH over the untreated control. At harvest, while the average bunch weight was highest in T_7 (427.63 g) followed by T_8 (401.47 g) over the control treatment T_1 (311.97 g). The weight of individual berry contributes for bunch weight via 50-berry weight. In the present study, 50-berry weight varied significantly among the different treatments. The treatment T_7 recorded maximum 50-berry weight (292.23 g) while it was lowest treatment in untreated control T_1 (261.90 g). Application of String's PH also resulted in increase in yield/vine, yield/acre and yield/ha. The treatment T_7 recorded highest yield/vine, yield/acre and yield/ha (19.43 kg/vine, 18.83 t/acre and 46.51 t/ha respectively). The performance of T_7 treatment was at par with treatment T_8, while the untreated control T_1 recorded lowest yield of 13.10 kg/vine, 12.70 t/acre and 31.37 t/ha respectively, indicating the significance of String's PH in improving the grape yield.

Effect of String's PH on berry quality parameters of Thompson Seedless

The grape quality mainly consists of berry length, berry diameter, TSS and acidity. The data recorded on grape berry quality is presented in Table 7. The differences for berry length among the different concentrations of string's PH were non-significant. Berry diameter varied significantly among the different treatments. The treatment T_7 recorded highest berry diameter (23.03 mm) which was at par with T_8 (22.23 mm) and T_6 (22.07 mm) whereas treatment T_2 showed lowest berry diameter (20.57 mm) as compared to the untreated control T_1 (19.60 mm). The quality of grapes considered for export is at 18.00 mm berry diameter. The differences for TSS among the different treatments were significant. TSS content was improved in all treated grapes as compared to control treatment. The maximum TSS was recorded in T_7 (18.20 °Brix) which was at par with T_8 (17.20 °Brix) as compared with commercial control T_2 (17.23 °Brix) and control T_1 (16.73 °Brix). The acidity in grape berries was within the acceptable limit in all the treatments.

Effect of String's PH on biochemical parameters of Thompson Seedless

The data recorded on phenol, tannin, reducing sugar, carbohydrate and protein is presented in Table 7. Phenol content was significantly higher in T_7 (0.99 mg/g Fresh Weight (FW)) while it was lowest in T_3 (0.32 mg/g FW) treatment as compared with untreated control T_1 (0.31 mg/g FW). Tannin content was significantly higher in T_5 (0.96 mg/g FW) followed by T_7 (0.92 mg/g FW) and lowest was observed in control T_1 (0.39 mg/g FW) Reducing sugar varied significantly among the different treatments. The treatments T_7 and T_4 recorded the highest reducing sugar (186.20 mg/g FW) which was at par with T_8 (184.87 mg/g FW) whereas treatment T_6 showed lowest reducing sugar (134.53 mg/g FW). The maximum carbohydrate was recorded in treatment T_7 (31.44 mg/g FW) while minimum carbohydrate (14.10 mg/g FW) was observed in treatment T_2. Protein was relatively higher in T_1 (2.06 mg/g FW) while it was lowest in T_2 (1.15

Table 6. Effect of String's PH on yield parameters of Thompson Seedless in Maharashtra

Treatment	Bunches/ Vine	Av. bunch weight (g)	No. of berries/bunch	50 berry weight (g)	Yield/vine (kg)	Yield/acre (t)	Yield/ha (t)
T_1	42.00	311.97	115.17	261.90	13.10	12.70	31.37
T_2	42.90	328.83	118.33	276.50	14.10	13.63	33.67
T_3	43.50	347.43	120.70	278.00	15.13	14.63	36.14
T_4	43.97	353.37	118.40	279.67	15.53	15.03	37.12
T_5	44.93	372.17	119.40	281.00	16.73	16.17	39.94
T_6	45.10	387.57	119.97	285.17	17.50	16.93	41.82
T_7	45.53	427.63	120.80	292.23	19.43	18.83	46.51
T_8	46.37	401.47	121.30	287.33	18.53	17.93	44.29
S Em ±	2.24	9.27	1.20	2.58	0.49	0.48	1.16
CD at 5 %	-	28.41	-	7.91	1.49	1.46	3.55
Sig	NS	**	NS	**	**	**	**

Table 7. Effect of String's PH on quality and biochemical parameters of Thompson Seedless in Maharashtra

Treatment	Berry diameter (mm)	Berry length (mm)	TSS (°Brix)	Acidity (%)	Phenol (mg/g FW)	Tannin (mg/g FW)	Reducing sugar (mg/g FW)	Carbohydrates (mg/g FW)	Protein (mg/g FW)
T_1	19.60	26.00	16.73	0.66	0.31	0.39	184.60	26.31	2.06
T_2	20.57	27.40	17.23	0.60	0.35	0.44	155.70	14.10	1.15
T_3	21.53	27.27	17.33	0.66	0.32	0.39	165.67	19.49	1.47
T_4	21.73	26.80	16.93	0.75	0.34	0.48	186.20	25.49	1.63
T_5	21.93	27.17	17.40	0.76	0.77	0.96	155.63	27.75	1.73
T_6	22.07	27.20	17.07	0.74	0.66	0.83	134.53	27.94	1.86
T_7	23.03	27.03	18.20	0.65	0.99	0.90	186.20	31.44	1.79
T_8	22.23	27.00	17.20	0.66	0.67	0.92	184.87	26.33	1.29
S Em ±	0.59	0.55	0.20	0.020	0.04	0.05	6.52	2.08	0.14
CD at 5 %	1.82	-	0.60	0.007	0.11	0.16	19.96	6.37	0.43
Sig	*	NS	**	**	**	**	**	**	**

mg/g FW) treatment.

Physiological loss in weight

The data on shelf life of grapes in terms of PLW (%) during storage at room temperature is presented in Fig. 1. In all the treatments, the PLW (%) increased with the advancement in storage duration. The minimum PLW (%) was recorded in treatment T_7 on 1st day (1.05 %), 2nd day (2.31 %), 3rd day (3.15 %), 4th day (4.20 %) and 5th day (5.25 %) respectively. PLW (%) in berries of control treatment on 1st day (1.93 %), 2nd day (2.91 %), 3rd day (3.89 %), 4th day (5.17 %) and 5th day (6.51 %). The pattern observed in different varieties at the other two locations also showed consistent trends, albeit with different values. The application of String's PH at varying concentrations can significantly influence the shelf-life of grapes by reducing decay and enhancing quality.

Discussion

Application of biostimulants resulted in improved berry diameter, berry length, bunch yield and healthy vine, which is crucial for sustainable viticulture. PHs has been reported to stimulate carbon and nitrogen metabolism thus enhancing nutrient assimilation and overall plant health (7). Previous studies in different crops established that PH application can lead to a significant increase in biomass accumulation, with reported increases of 6.8–21.3 % in aerial parts under varying water conditions (15). The observed increase in berry weight aligns with findings in a previous study (5), who also noted that PH biostimulants increased berry size by enhancing nutrient uptake under stress. Our results are in line with the findings of (3–5), who reported that biostimulant application significantly increased average bunch weight, 50-berry weight and yield per vine in Sharad Seedless and Thompson Seedless grape varieties, respectively, under the Pune conditions in Maharashtra.

Application of PH has been shown to increase berry diameter by up to 9.5 % under water stress conditions (15). Enhanced root development and nutrient uptake from PH contribute to increased berry length and overall fruit size (16). Similar findings were reported by (3–5) who observed that the application of biostimulants significantly increased berry length and diameter in Sharad Seedless and Thompson Seedless grapevines, respectively. However, no notable effect on TSS was observed under the agro-climatic conditions of Pune, Maharashtra.

PH improves the synthesis of sugars and organic acids, resulting in higher TSS levels in grapes (17). The balance of TSS and acidity is crucial for grape quality; PH helps to maintain this balance, enhancing flavor profiles (18).

Phenolic compounds, as essential plant metabolites, contribute significantly to several physiological processes that are vital for the health and development of the plant (19). Additionally, biostimulants, including seaweed extracts, have been found to substantially elevate phenolic content across different plant parts, such as fruits, leaves and roots. This increase positively influences fruit quality, elevates sugar levels and enhances antioxidant capacities (20). Furthermore, these biostimulants optimize nitrogen metabolism, leading to improved protein synthesis and greater sugar accumulation, especially under conditions of stress, thereby boosting plant resilience and productivity (18). The present findings are consistent with previous studies (3–5), which reported that biostimulant application significantly enhanced biochemical parameters such as phenols, proteins, reducing sugars and carbohydrates in Sharad Seedless and Thompson Seedless grapevines, respectively, under the climatic conditions of Pune, Maharashtra.

Research indicates that specific PH, such as soy and casein, effectively reduce gray mould incidence, a major factor in grape spoilage, with optimal concentrations around 0.8 g/L showing the best results (21). Additionally, pre-harvest treatments with jasmonic acid (JA) and grapefruit seed extract have been shown to improve grape quality and storability, with JA at 8 mM yielding the lowest decay rates (22). Furthermore, studies on the foliar application of biostimulants at various phenological stages have proven effective in reducing physiological weight loss (%) in Sharad Seedless and Thompson Seedless grape varieties, as reported by (3–5) respectively.

Conclusion

A field experiment was conducted to evaluate the efficacy of String's PH biostimulant, Grepa in grapes following forward pruning. The study was carried out across multiple locations in Telangana, Karnataka and Maharashtra, representing different agroecological

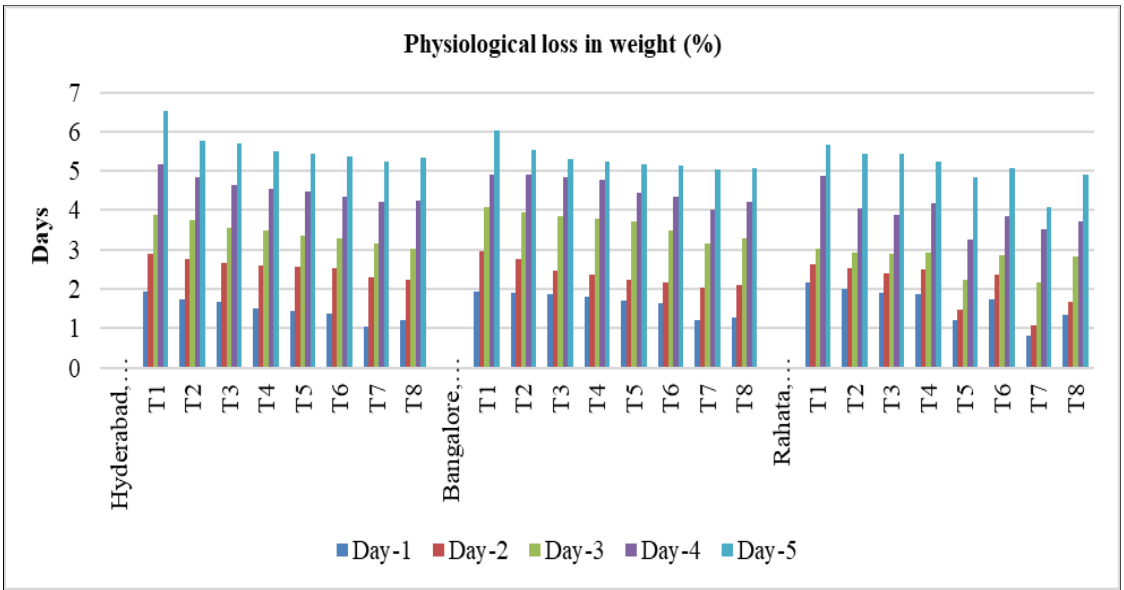

Fig. 1. Effect of String's protein hydrolysate on physiological loss in weight (%).

zones in India. String's PH were applied as foliar sprays at different doses. All treatments with String's PH significantly improved grape yield and berry quality compared to both the commercial and untreated controls. Among the treatments, T_7 (String's PH at 5 mL/L) consistently demonstrated superior performance in terms of yield, berry quality and shelf-life across all three regions. These findings suggest that the T_7 treatment (5 mL/L) is optimal for improving grape yield, quality and shelf-life.

Acknowledgements

The authors are thankful to the Director, ICAR- National Research Centre for Grapes, Pune for providing facilities to conduct research.

Authors' contributions

RGS was responsible for conceptualization, experimental design and editing of the manuscript. PBK conducted the research and handled data acquisition, data analysis, statistical analysis and final drafting of the manuscript. SPM assisted with data analysis and drafting of the manuscript. CB contributed to editing the manuscript. VS supported data acquisition and assisted in statistical analysis. SRK and GJP helped in conducting the experiment and data collection. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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