PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–10
https://doi.org/10.14719/pst.5553

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Optimizing hill banana (*cv*. Virupakshi) production: Impact of biostimulants on yield, quality and shelf life, unveiling its phytochemical profile using GC-MS analysis and its pharmacological activity

Chinnasamy C S[1], Rajangam J[2], Kalpana K[3]*, Balakumbahan R[4], Venkatesan K[5], Anitha T[6], Muthuramalingam S[1], Sankar C[1] & Kabilan M[7]

[1]Department of Fruit Science, Horticultural College & Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni 625 604, Tamil Nadu, India
[2]Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni 625 604, Tamil Nadu, India
[3]Department of Plant Protection, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni 625 604, Tamil Nadu, India
[4]Horticultural Research Station, Tamil Nadu Agricultural University, Thadiyankudisai, Dindigul 624 212, Tamil Nadu, India
[5]Department of Floriculture & Landscaping, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Theni 625 604, Tamil Nadu, India
[6]Department of Post-Harvest Technology, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni 625 604, Tamil Nadu, India
[7]Department of Vegetable Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni 625 604, Tamil Nadu, India

*Email: kalpana.k@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY

Received: 05 October 2024
Accepted: 15 October 2024

Available online
Version 1.0 : 25 November 2024

Additional information

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

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Chinnasamy C S, Rajangam J, Kalpana K, Balakumbahan R, Venkatesan K, Anitha T, Muthuramalingam S, Sankar C, Kabilan M. Optimizing hill banana (*cv*. Virupakshi) production: Impact of biostimulants on yield, quality and shelf life, unveiling its phytochemical profile using GC-MS analysis and its pharmacological activity. Plant Science Today.2024;11(sp4):01-10. https://doi.org/10.14719/pst.5553

Abstract

This study assessed the impact of various biostimulants on the yield and quality of hill banana (*Musa* sp.) cv. Virupakshi in Kilakuchettipatti, Kodaikanal Taluk, Tamil Nadu, during 2023-2024. A Randomized Block Design (RBD), different concentrations of biostimulants were tested, including seaweed extract (2 % and 3 %), fulvic acid (2 % and 3 %), panchagavya (2 % and 3 %), moringa leaf extract (2 % and 4 %), protein hydrolysate (1 % and 2 %), vermiwash (2 % and 3 %) and orthosilicic acid (2 % and 4 %), along with a control group. The 3 % seaweed extract was the most effective, significantly improving yield and quality parameters compared to the control, which had lower acidity and higher values in bunch weight, bunch length, hand weight, finger length, pulp weight, peel weight, peel thickness, TSS, total sugars, reducing sugars and non-reducing sugars. The study also analyzed the phytochemical profile of bananas treated with 3 % seaweed extract, revealing enhancements in bioactive compounds like benzopyran, coumarin, allyl urea, and allyl alcohol, known for their antioxidant and antimicrobial properties. Additionally, the seaweed extract contained 40 major bioactive compounds, with 16 highlighted for their pharmaceutical activity. These findings suggest that biostimulants can enhance the nutritional and health benefits of bananas and improve cultivation practices.

Keywords

Hill banana; Viupakshi; biostimulants; GC-MS; bioactive compounds

Introduction

Banana (*Musa* sp.) is one of the major fruit crops grown in tropical and subtropical regions of the world. It is a highly valued and exportable product. Bananas are grown in over 150 countries and are regarded as the fourth staple food after rice, maize and wheat, yielding 110 million tons of banana fruit annually (1, 2). Bananas are the second most important fruit crop in India, after mangoes. Their popularity is due to their year-round availability, delicious taste, low cost and rich nutritional content. Fruits and vegetables are vital for health, strengthening the body's defenses against numerous diseases. Because of their nutritional richness, fruits are a vital part of the diet. They are essential for the body's defense system and boost the immune system's ability to fight off various diseases (3). India is the largest banana producer in the world, followed by China, the Philippines, Brazil and Ecuador. As of 2022, India produces 29.895 million tonnes of bananas on 0.837 million ha. About 87 % of global banana production is grown by small-scale farmers for domestic use, while the remaining 13 %, mostly dessert bananas are exported. The state with the highest banana production in India is Maharashtra, which produces 3924.1 million tonnes, followed by Tamil Nadu, which produces 3543.8 million tonnes. Bananas account for 13 % of the total fruit cultivation area and 33 % of fruit production in the country (4).

Hill bananas, known for their aroma, nutrition and taste, are grown in Lower Pulney Hills has a Geographical Indications (GI) tag number of 124. Bananas are a highly nutritious fruit that provides instant energy and various health benefits due to their rich carbohydrate, vitamin and mineral content, especially potassium. They can lower heart attack risk, support cell metabolism and offer other health advantages. Biostimulants, whether natural or synthetic, enhance plant growth and stress resistance, improve nutrient uptake and reduce reliance on chemicals. These include substances like seaweed extracts, humic materials and amino acids. For banana cultivation, especially the Virupakshi variety in the Lower Pulney Hills, biostimulants can increase yield, quality and shelf life, overcoming growth challenges and supporting sustainable agricultural practices. Gas chromatography-mass spectrometry (GC-MS) is vital for the qualitative and quantitative analysis of phytoconstituents in plant extracts, offering detailed and accurate chemical analysis of plan based medicines (5). The top-quality banana pulp was subjected to GC-MS analysis. Taking into consideration this study investigates the effect of bio stimulants on the yield and quality of hill bananas as well as the bioactive compounds in hill bananas.

Materials and Methods

Collection of samples

The study was conducted during 2023-24 in Kilakkuchettipatti, part of the Kodaikanal taluk in Lower Pulney Hills of Western Ghats in Tamil Nadu. The study used a Randomized Block Design with 15 treatments and 3 replications including various concentrations of seaweed extract, fulvic acid, panchagavya, moringa leaf extract, protein hydrolysate, vermiwash, orthosilicic acid and control. Five plants per treatment were tagged at the last hand opening stage and received three foliar sprays at specified intervals.

Yield and quality attributes

The study on Virupakshi Hill bananas was conducted at the farmer's field located at Kilakkuchettipatty, Kodaikanal taluk, Dindigul district, Tamil Nadu, India using a randomized complete block design with 3 replications. Banana bunches were subjected to different concentrations of biostimulants, including seaweed extract, moringa leaf extract, fulvic acid, panchakavya, vermiwash, protein hydrolysate and orthosilicic acid. Yield parameters such as bunch weight, bunch length, number of hands per bunch, hand weight, number of fingers per hand, total number of fingers per bunch and finger length and quality parameters such as total soluble solids pulp weight, peel weight, peel thickness, TSS, total sugars, titrable acidity, reducing sugars, non-reducing sugars and shelf life were analyzed (6).

Extraction and preparation of Virupakshi banana pulp powder

Banana fruits were washed in the laboratory with running tap water, surface sterilized with 70 % alcohol and rinsed with sterile distilled water. The peels were removed and cut into small pieces. The banana peels were dried in the oven at 40 °C for 24 h. The dried banana peels were ground using a household grinder to obtain a fine powder and stored in sealed plastic bags at 4 °C until further use. Banana pulp was extracted with methanol, homogenized, centrifuged and filtered to obtain a clear supernatant. This extract was concentrated and prepared for GC-MS analysis. The method effectively revealed the bioactive components in the banana pulp extract. Virupakshi banana pulp powder was placed in conical flasks and extracted with methanol at a weight/volume ratio of 1:8. The mixture was agitated at 155 rpm for 24 h on an orbital shaker. After extraction, the mixture was filtered through Whatman filter paper No. 40 (120 mm) to separate the solvent layer. The resulting filtrate was then prepared for further analysis (7).

Gas chromatography-mass spectrometry (GC-MS) analysis

For GC-MS analysis, the Virupakshi banana pulp powder was combined with methanol in a sealed flask and allowed to infuse for 24 h. The mixture was then filtered and the solvent was evaporated using a vacuum distillation apparatus. The residue obtained was analyzed using a Thermo GC Ultra Clarus 550 system, which integrates a gas chromatograph with a mass spectrometer. The system featured an elite-I fused RMS 6 silica capillary column and used electron ionization set to 60 eV. A 1 µL sample was injected with a 12:1 split ratio and helium (99.9 %) was used as the carrier gas at a constant flow rate of 2 mL/min. The ion source and injector temperatures were set to 230 °C and 240 °C respectively. The oven temperature program began at 90 °C, increased by 5 °C per min to 240 °C and then held isothermal for 3 min. Mass spectra were recorded for fragments ranging from 50 to 650 Da, with a scan interval of 0.5 sec. Turbo Mass software was used to analyze the mass spectra and chromatograms and the % composition of each component was determined by comparing the average peak area of each to the total peak area (8).

Identification of bioactive compounds

The mass spectra obtained from the GC-MS analysis were interpreted using the National Institute of Standards and Technology (NIST) database, which includes retention values for over 95000 compounds and the Wiley library. This method allowed for the identification of unknown components by matching them with known substances, determining their molecular weight and analyzing their composition.

Biological activity of identified substances

Predictions about the biological effects of the identified compounds were made using the PASS (Prediction of Activity Spectra for Biologically Active Substances) database based on their structural formulas. This process involved forecasting various pharmacological effects, potential toxicities and possible modes of action related to the compounds (9, 10).

Statistical analysis

The data were analyzed statistically using standard methods. This involved performing an analysis of variance (ANOVA), calculating the standard error of the difference (SE (d)) and determining the critical difference at a significance level of 5 % ($p = 0.05$).

Results

Yield attributes

The application of different biostimulants resulted in significant variations in bunch weight. The highest bunch weight (14.10 kg) was achieved with 3 sprays of 3 % seaweed extract (T_2). The second highest bunch weight (13.71 kg) was observed with 4 % moringa leaf extract (T_8). In contrast, the untreated control (T_{15}) recorded the lowest bunch weight at 6.83 kg. Bunch length exhibited a similar trend to bunch weight. The longest bunch length of 80.49 cm was obtained with three sprays of 3 % seaweed extract (T_2) (Fig. 1 and 2). The control (T_{15}) resulted in the shortest bunch length of 50.39 cm. The application of biostimulants did not significantly alter the number of hands per bunch. Hand weight, a crucial yield attribute, was significantly affected by the biostimulant treatments. The highest hand weight (1.45 kg) was recorded with three sprays of 3 % seaweed extract (T_2), followed by 4 % moringa leaf extract (T_8) with a hand weight of 1.32 kg. The control group (T_{15}) had the lowest hand weight at 0.51 kg. There were no significant variations in the number of fingers per hand due to

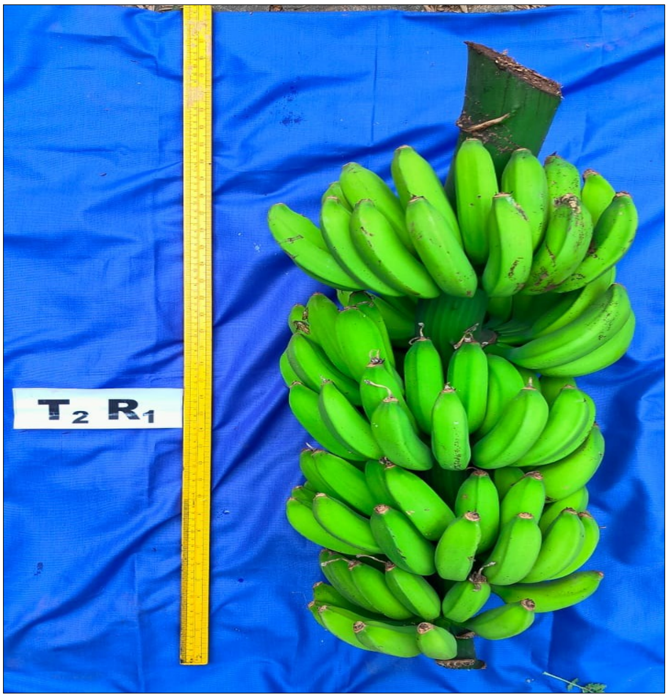

Fig. 1. Banana bunch treated with 3 % seaweed extract.

Fig. 2. Banana bunch untreated (Control).

biostimulant treatments. The number of fingers per bunch did not show significant variations among treatments. Finger length, a key indicator of fruit quality, was significantly improved by the 3 % seaweed extract (T_2), with a length of 17.10 cm. The 4 % moringa leaf extract (T_8) followed closely with a finger length of 15.80 cm. The control group had the shortest finger length (10.50 cm) as shown in Table 1.

Quality characters

The application of biostimulants had a significant impact on pulp weight. The highest pulp weight of 51.85 g was recorded with 3 sprays of 3 % seaweed extract (T_2), closely followed by 4 % moringa leaf extract (T_8) with a pulp weight of 51.86 g. The control group, which did not receive any biostimulants, had the lowest pulp weight at 20.51 g. Peel weight also showed significant variations due to biostimulant treatments. The 3 % seaweed extract (T_2) resulted in the highest peel weight (23.54 g), followed by 4 % moringa leaf extract (T_8) with a peel weight of 19.74 g. The control group recorded the lowest peel weight at 14.86 g. Peel thickness followed a similar trend to peel weight. The maximum peel thickness (3.83 mm) was observed in fruits treated with 3 % seaweed extract (T_2), while fruits treated with 4 % moringa leaf extract (T_8) had a peel thickness of 3.56 mm. The control group exhibited the lowest peel thickness at 1.91 mm.

Total soluble solids were highest in fruits treated with 3 % seaweed extract (T_2), with a TSS value of 15.33. This was closely followed by 4 % moringa leaf extract (T_8) with a TSS of 15.10. The control group recorded the lowest TSS at 11.90. Total sugars mirrored the trend observed in TSS. The highest total sugar content (18.95 %) was found in fruits treated with 3 % seaweed extract (T_2), closely followed by 4 % moringa leaf extract (T_8) with 18.65 %. The control group had the lowest total sugar content at 13.35 %. Titratable acidity was significantly lower in fruits treated with 3 % seaweed extract (T_2), showing an acidity of 0.25 %. This was followed by 4 % moringa leaf extract (T_8) with an

Table 1. Effect of biostimulants on yield parameters of hill banana cv. Virupakshi.

Treatments	Bunch weight (kg)	Bunch length (cm)	No. of hands/ bunch	Hand weight (kg)	No. of fingers / hand	No. of fingers/ bunch	Finger length (cm)
T_1	11.62	69.19	7.79	0.99	15.21	78.32	12.89
T_2	14.10	80.49	7.95	1.46	15.75	82.10	17.10
T_3	10.35	62.70	7.65	0.89	14.75	77.95	12.80
T_4	12.55	72.40	7.82	1.17	15.69	81.61	15.79
T_5	8.70	54.80	6.50	0.52	13.57	76.65	12.29
T_6	10.37	68.30	7.69	0.96	14.95	78.15	13.30
T_7	10.10	62.40	7.62	0.86	14.60	77.87	15.20
T_8	13.70	74.70	7.92	1.32	15.64	81.85	15.80
T_9	7.45	51.29	7.44	0.62	13.48	75.40	11.59
T_{10}	9.80	59.60	6.54	0.79	13.90	76.92	11.40
T_{11}	9.80	60.50	6.58	0.83	13.95	77.26	11.00
T_{12}	11.20	70.50	7.85	1.01	15.59	79.43	13.50
T_{13}	8.15	53.60	5.46	0.72	13.55	76.12	13.69
T_{14}	9.12	55.40	6.51	0.65	13.71	76.79	12.40
T_{15}	6.83	50.39	5.59	0.51	12.90	75.30	10.50
Mean	10.26	63.08	7.13	0.89	14.48	78.11	13.28
SE (d)	0.21	1.46	0.15	0.26	0.24	0.15	0.20
C.D (p=0.05)	0.44	3.01	NS	0.53	NS	NS	0.41

T_1: Sea weed extract (2 %), **T_2**: Sea weed extract (2 %), **T_3**: Fulvic acid (2 %), **T_4**: Fulvic acid (3 %), **T_5**: Panchakavya (2 %), **T_6**: Panchakavya (3 %), **T_7**: Moringa leaf extract (2 %), **T_8**: Moringa leaf extract (4 %), **T_9**: Protein hydrolysate (1 %), **T_{10}**: Protein hydrolysate (2 %), **T_{11}**: Vermiwash (2 %), **T_{12}**: Vermiwash (3 %), **T_{13}**: Ortho-silicic acid (2 %), **T_{14}**: Orthosilicic acid (4 %), **T_{15}**: Control.

acidity of 0.27 %. The control group had the highest acidity level at 0.54 %. Reducing sugars were highest in fruits treated with 3 % seaweed extract (T_2) at 11.15 %, followed closely by 4 % moringa leaf extract (T_8) at 11.11 %. The control group had the lowest reducing sugar content at 8.21 %. Non-reducing sugars were also highest in fruits treated with 3 % seaweed extract (T_2), with a content of 7.41 %. The next highest non-reducing sugar content was found in fruits treated with 2 % Fulvic acid (T_3) at 7.22 %. The control group had the lowest non-reducing sugar content at 4.88 %, as represented in Table 2.

Shelf life of fruits

The study demonstrates that pre-harvest applications of

Table 2. Effect of biostimulants on quality parameters and shelf life of hill banana *cv.* Virupakshi.

Treatments	Pulp weight (g)	Peel weight (g)	Peel thickness (mm)	TSS (brix)	Total sugars (%)	Titrable acidity (%)	Reducing sugars (%)	Non-reducing sugars (%)	Shelf life (days)
T_1	43.79	18.89	2.45	13.98	17.63	0.50	10.56	6.72	10.40
T_2	63.84	23.54	3.83	15.33	18.95	0.25	11.15	7.41	11.30
T_3	38.376	16.34	2.80	13.87	17.48	0.55	9.88	7.22	9.60
T_4	49.86	18.64	2.91	14.93	18.17	0.33	10.94	6.87	10.70
T_5	36.37	19.34	2.46	12.21	14.98	0.54	9.20	5.49	8.60
T_6	38.98	18.58	2.48	13.88	17.51	0.50	10.16	6.98	10.39
T_7	33.99	14.59	2.38	13.67	16.70	0.54	9.66	6.69	9.30
T_8	51.86	19.74	3.56	15.10	18.65	0.27	11.11	7.16	10.90
T_9	32.28	15.91	2.19	11.93	13.77	0.58	8.59	4.92	8.50
T_{10}	32.84	13.75	2.34	13.25	15.86	0.56	8.92	6.59	9.20
T_{11}	29.56	19.81	2.35	13.42	16.66	0.51	9.47	6.83	9.20
T_{12}	46.59	19.63	2.33	14.11	17.91	0.45	10.75	6.80	10.50
T_{13}	29.94	18.37	3.13	12.06	14.25	0.56	8.70	5.27	8.30
T_{14}	28.47	16.75	2.17	12.60	15.11	0.59	8.78	6.01	9.10
T_{15}	20.51	14.86	1.91	11.90	13.35	0.60	8.21	4.88	8.10
Mean	38.48	17.92	2.62	13.48	16.46	0.49	9.74	6.39	9.61
SE(d)	0.86	3.34	0.05	0.33	0.37	0.01	0.24	0.14	0.19
C.D (p =0.05)	1.78	0.70	0.11	0.68	0.77	0.02	0.50	0.29	0.40

T_1: Sea weed extract (2 %), **T_2**: Sea weed extract (2 %), **T_3**: Fulvic acid (2 %), **T_4**: Fulvic acid (3 %), **T_5**: Panchakavya (2 %), **T_6**: Panchakavya (3 %), **T_7**: Moringa leaf extract (2 %), **T_8**: Moringa leaf extract (4 %), **T_9**: Protein hydrolysate (1 %), **T_{10}**: Protein hydrolysate (2 %), **T_{11}**: Vermiwash (2 %), **T_{12}**: Vermiwash (3 %), **T_{13}**: Ortho-silicic acid (2 %), **T_{14}**: Orthosilicic acid (4 %), **T_{15}**: Control.

biostimulants can significantly enhance the shelf life of hill bananas. The 3 sprays of 3 % seaweed extract (T_2) were the most effective, extending the shelf life to 11.30 days. The 4 % moringa leaf extract (T_8) also improved shelf life but was slightly less effective, with a shelf life of 10.90 days (Fig. 3 and 4). The control group exhibited the shortest shelf life at 8.10 days as shown in Table 2.

Fig. 3. Shelf life of banana seaweed 3 % treated at 10th day.

Fig. 4. Shelf life of banana untreated (Control) at 7th day.

Bioactive compounds identified by GC-MS and their health benefits for individuals

The study identified 40 bioactive compounds in banana pulp using optimized extraction and GC-MS analysis (Table 3). These compounds are known for their antioxidant, anti-inflammatory and antimicrobial properties, which highlight banana pulp's potential health benefits. The findings suggest that banana pulp could be valuable in developing functional foods, dietary supplements and therapeutic products. GC-MS proved effective in revealing the detailed chemical profile of banana pulp, enhancing our understanding of its nutritional value and health-promoting potential (Table 4 and Fig. 5). Plant extracts and their compounds are recognized for their biological activities, particularly their antimicrobial and antioxidant properties (11). Some of the peaked compounds were benzodiazoborine, pyranone, propanol, coumarin, allyl urea and allyl alcohol, contributing more area.

Discussion

The observed increase in yield and yield attributes can be attributed to the presence of phytohormones and growth regulators in seaweed extract, which acts as a biostimulant. seaweed acts as a biomodulator. These compounds likely contribute to enhanced fruit weight and size by stimulating cell enlargement and division. This effect may occur individually or collectively, leading to improved overall fruit development and productivity (12) and it is followed by moringa leaf extract, which enhances fruit weight, length and circumference due to its high potassium and zinc content. Potassium facilitates carbohydrate formation and transport, improving fruit quality (13), while zinc aids in fruit growth by contributing to indole acetic acid production (14).

The application of seaweed extract and moringa leaf extract has shown notable improvements in the physiological traits and quality attributes of banana plants. Seaweed extract functions as a potent biostimulant, enhancing nutrient uptake, boosting root development and increasing fruit weight by around 8 % (15). In parallel, moringa leaf extract promotes robust plant growth and elevates fruit quality, primarily through increased vitamin C production in the leaves, which benefits the fruit. The combined application of these biostimulants not only improves yield but also enhances the overall health and quality of banana crops, making them essential for sustainable banana cultivation (16).

The application of 3 % seaweed extract has been demonstrated as an effective organic amendment that positively impacts the quality of Hill Banana (*Musa* sp.) crops. Different plant parts, once traditionally used for microbial control, have now been shown to effectively manage microbial infections (17). Plants yield various chemicals from their different parts, such as bark, leaves,

Table 3. Different bioactive compounds present in hill banana pulp (seaweed treated) with peak number, peak area, compound name, retention time and molecular formula.

Peak number	Compound	Molecular formula	Peak area (%)	RT (min)
1	2-Imino-6-nitro-2H-1-benzopyran-3- carbothioamide	$C_{10}H_8N_2OS$	3.36	4.187 min
2	2-Propen-1-ol	C_3H_6O	11.02	5.086 min
3	3(2H)-Furanone, dihydro-5-isopropyl	$C_7H_{12}O_2$	0.88	5.498 min
4	3H-Pyrazol-3-one, 2,4-dihydro-2,4,5-trimethyl thymine	$C_4H_6N_2O$	2.22	5.620 min

5	Urea, 2-propenyl	$C_4H_8N_2O$	3.56	6.020 min
6	2,3,1-Benzodiazaborine, 1,2-dihydro-1-methyl	$C_8H_9BN_2$	6.76	6.364 min
7	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl	$C_6H_8O_4$	14.50	6.486 min
8	Benzene, 1-chloro-3-methoxy	C_7H_7ClO	1.29	6.597 min
9	1,3,2-Dioxaborolan-4-one, 2-ethyl-5-methyl	$C_5H_9BO_3$	1.29	6.809 min
10	Silane, ethenylethyl dimethyl	$C_6H_{12}Si$	1.07	6.942 min
11	1-Methoxy-1-buten-3-yne	C_5H_6O	6.60	7.164 min
12	2-Butyndiol dimethyl ether	$C_6H_{14}O_2$	9.05	7.220 min
13	1,2-Benzenediol, 4-methyl	$C_7H_8O_2$	1.31	7.431 min
14	2,5-Octadiene	C_8H_{14}	0.32	7.786 min
15	4-Pentyn-1-ol	C_5H_8O	0.33	7.908 min
16	Benzene acetaldehyde, alpha,2,5-trimethyl	$C_9H_{10}O$	0.71	8.386 min
17	5,6-Epoxy-6-methyl-2-heptanone	$C_8H_{14}O_2$	2.28	8.753 min
18	4-Amino-1-methyl-5-nitropyrazole	$C_4H_6N_4O_2$	0.33	8.853 min
19	2-Pyridinemethanol, 3-hydroxy hydrochloride	$C_6H_8ClNO_2$	0.34	9.053 min
20	Butoxyacetic acid	$C_6H_{12}O_3$	0.50	9.175 min
21	Oxirane, 2-ethyl-2-methyl	$C_5H_{10}O$	3.94	9.386 min
22	Butanoic acid, 3-hydroxy-, ethyl ester	$C_6H_{12}O_3$	1.17	9.486 min
23	t-Butyl 1-thio-1-desoxy-beta-D-glucopyranoside	$C_{10}H_{20}O_5S$	3.12	9.575 min
24	2-Isopropoxyethyl propionate	$C_8H_{16}O_3$	3.14	9.741 min
25	Benzoic acid, 4-ethoxy-, ethyl ester	$C_{11}H_{14}O_3$	3.58	9.797 min
26	Thiocyanic acid, 2-(2-butoxyethox) ethyl ester	$C_9H_{17}NO_2S$	6.47	9.897 min
27	Methyl 2,6-anhydro-alpha-d-altroside	$C_7H_{12}O_5$	1.46	10.108 min
28	Diethyl Phthalate	$C_{12}H_{14}O_4$	0.32	10.308 min
29	alpha-D-Glucopyranoside, methyl	$C_7H_{14}O_6$	1.14	10.830 min
30	3-Deoxy-d-mannoic lactone	$C_6H_{10}O_5$	0.43	10.919 min
31	midazole, 2-fluoro-5-hydroxy-1-ribofuranosyl	$C_8H_{11}FN_2O_5$	1.34	10.986 min
32	1-(Methylthio)-2-butene	$C_5H_{10}S$	0.39	11.108 min
33	beta-D-Glucopyranose, 4-O-beta-D-galactopyranosyl	$C_{12}H_{22}O_{11}$	1.22	11.208 min
34	Diphenyl sulfone	$C_{12}H_{10}O_2S$	0.56	12.863 min
35	Tridecanoic acid	$C_{13}H_{26}O_2$	0.86	12.919 min
36	Octadecanoic acid	$C_{18}H_{36}O_2$	0.38	14.196 min
37	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl-	$C_{16}H_{50}O_7Si_8$	0.94	18.151 min
38	2,4-Di-tert-butyl-6-(tert-butylamino) phenol	$C_{18}H_{31}NO$	0.39	18.218 min
39	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl	$C_{16}H_{50}O_7Si_8$	0.47	18.296 min
40	beta-Sitosterol	$C_{29}H_{50}O$	0.95	22.162 min

roots, seeds and fruits (18). Since ancient times, plant-derived natural products have been used to promote and maintain human health (19). Seaweed extract 3 % treatment enhances the levels of bioactive compounds and phytochemicals in banana pulp, resulting in notable improvements in plant physiology. Seaweed extracts, as organic amendments, have been shown to increase crop quality by improving nutritional attributes and enhancing

Table 4. Major bioactive compounds identified by GC-MS and its pharamaceutical activity.

Sl. No.	Compound identified	Common name	Pharmaceutical activity	Reference
1.	2-imino-6-nitro-2H-1-benzopyran-3- carbothioamide	Benzopyran	Exhibit antioxidant, anti-inflammatory, antimicrobial and anticancer properties and neutralize harmful free radicals, manage inflammatory disorders, treat infections and potentially serve in cancer therapy.	(26-29)
2.	2-propen-1-ol	Allyl alcohol	Found in garlic, have shown potential in treating conditions like hypertension, hypercholesterolemia, diabetes, rheumatoid arthritis and may aid in preventing atherosclerosis and tumor development and cell death to many human pathogens.	(30, 31)
3.	3(2H)-furanone, dihydro-5-isopropyl	Dihydroisocoumarin	Antioxidant and anti-inflammatory properties, which are useful for managing oxidative stress-related conditions, anti- inflammatory diseases and it also has potential antimicrobial and antialzheimer's effects.	(32)
4.	3H-pyrazol-3-one, 2,4-dihydro-2,4,5-trimethyl thymine	2, 4-dihydro-2,4,5-trimethylthymine (DTT)	Antioxidant properties and shows potential as an anticancer agent by inducing apoptosis and inhibiting tumor growth and antimicrobial, antipyretic, anti-inflammatory and antitumor activities.	(33-35)

5.	Urea, 2-propenyl	Allyl urea	Acts as a diuretic, promoting increased urine production and excretion, which can be beneficial for treating conditions such as edema, hypertension and certain kidney disorders and inhibiting the growth of specific cancer cells.	(36, 37)
6.	2,3,1- benzodiazaborine	Diazaborine	Treating inflammatory diseases and antimicrobial properties.	(38, 39)
7.	4H-pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl	2,3-dihydro-3,5-dihydroxy -6-methyl-4-pyrone	Anti-inflammatory and antioxidant properties and promise for improving conditions such as osteoporosis, diabetes and cardiovascular diseases.	(40)
8.	1-methoxy-1-buten-3-yne	1-buten-3-yne, 1-methoxy	Useful in medicinal chemistry and creating biologically active molecules.	(41)
9.	2-butyndiol dimethyl ether	Benzodiazaborine	Exhibited strong antifungal activity against various pathogenic fungi.	(42)
10.	Oxirane, 2-ethyl-2-methyl	Dimethyloxirane	Antitumor, antimalarial and antifungal activities.	(43, 44)
11.	t-butyl 1-thio-1-desoxy-beta-D-glucopyranoside	Glucopyranoside	Regulate glucose absorption in the kidneys and reduces blood glucose levels.	(45)
12.	2-isopropoxyethyl propionate	Isopropyl propanoate	Improving skin health and preventing signs of aging.	(46)
13.	Thiocyanic acid, 2-(2-butoxyethox) ethyl ester	Butoxyethoxy ethyl thiocyanate	Antifungal and antibacterial effect.	(47)
14.	N- tridecanoic acid	Tridecanoic acid	Serves as an effective antipersister, antibiofilm agent and demonstrating strong antibacterial properties against various pathogens.	(48)
15.	Octadecanoic acid	Octadecanoic acid	Improving moisture retention, supporting the skin barrier and potentially providing anti-inflammatory effects and better skin hydration and enhanced absorption of other skincare ingredients.	(49, 50)
16.	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15, 15-hexadecamethyl	Hexadecamethyloctasiloxane	Antibacterial properties, especially against Staphylococcus agalactiae for treating bacterial infections in individuals with compromised immunity and oxidative stress conditions and antioxidant activities.	(51, 52)

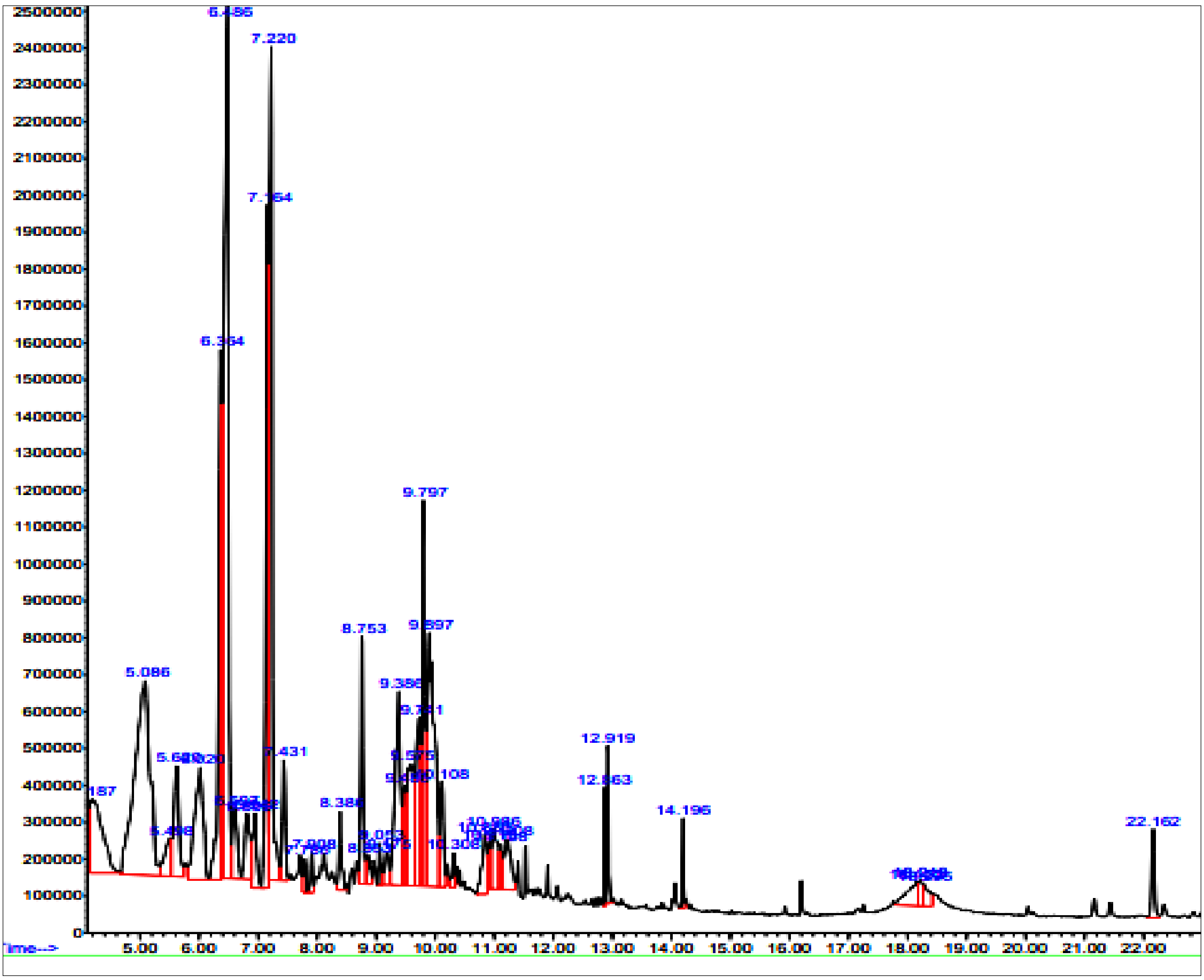

Fig. 5. Total ion chromatogram (TIC) of seaweed treated banana pulp using GC-MS profiling.

stress resilience. This improvement is likely due to increased enzyme activity, better nutrient uptake and optimized metabolic pathways facilitated by the seaweed extract leading to a more favorable growth environment for the accumulation of beneficial phytochemicals (20). Further elucidation of the seaweed extract's impact on banana quality was achieved through GC-MS analysis. GC-MS effectively identifies and quantifies volatile and semi volatile compounds, providing detailed insights into the nutritional and health-promoting properties of bananas (7).

The analysis revealed a range of bioactive compounds including phenolics, flavonoids and polyphenolic compounds known for their antioxidant and anti-inflammatory benefits (21). The findings underscore the role of seaweed extract in enhancing the fruit's nutritional profile by increasing bioactive compound levels and improving overall physiological health by organic amendments, as evidenced by a research (22). The investigation shows that integrating seaweed extract into bananas offers a novel approach to significantly enhancing the fruit's therapeutic efficacy. Bananas are rich in bioactive compounds such as 2-imino-6-nitro-2H-1-benzopyran-3-carbothioamide and 2-propen-1-ol, possess notable antioxidant, anti-inflammatory, antimicrobial and anticancer properties (23) as explored in Table 4.

The addition of seaweed extract, which is high in polysaccharides, vitamins, minerals and antioxidants like fucoidan and laminarin, further amplifies these benefits. Seaweed extract helps neutralize reactive oxygen and nitrogen species, which is crucial for managing oxidative stress and chronic diseases such as diabetes, cardiovascular disorders and cancer (24).

The combined bioactive effects of seaweed and bananas can enhance antioxidant defenses, improve inflammatory and antimicrobial responses and potentially boost cancer prevention and skin health (25). This synergistic effect highlights the potential of 3 % seaweed extract -treated bananas as a functional food with expanded therapeutic applications, although further research is needed to fully understand and optimize these interactions for health promotion and disease prevention.

Conclusion

The study demonstrates the significant benefits of biostimulants, particularly 3 % seaweed extract, on the yield, quality and bioactive compounds of Virupakshi hill banana. This biostimulant significantly outperformed control treatments, which exhibited higher acidity and lower quality metrics. GC-MS analysis identified 40 bioactive compounds, with 16 noted for their potential medicinal benefits, underscoring the extract's value in promoting health and wellness.

Acknowledgements

Authors acknowledge the support rendered by the Department of Fruit Science, Horticultural College and Research Institute, Periyakulam and Horticultural Research Station, Thadiyankudisai, Tamil Nadu Agricultural University, Tamil Nadu, for providing the necessitated facilities during the course of research work.

Authors' contributions

CRK was responsible for the conceptualization and writing of the original draft, while BVA revised the draft, incorporated tables and figures, and conducted proofreading. MS contributed to the revision, formatting, and overall supervision of the manuscript. All authors reviewed and approved the final version of the manuscript.

Compliance with ethical standards

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

Ethical issues: None

AI Declaration

While preparing the manuscript, the authors used Grammarly to improve the language and readability. After using this tool/ service, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

References

1. Sitthiya K, Devkota L, Sadiq MB, Anal AK. Extraction and characterization of proteins from banana (*Musa sapientum* L.) flower and evaluation of antimicrobial activities. Journal of Food Science and Technology. 2018;55:658-66. https://doi.org/10.1007/s13197-017-2975-z
2. Falcomer AL, Riquette RFR, de Lima BR, Ginani VC, Zandonadi RP. Health benefits of green banana consumption: A systematic review. Nutrients. 2019;11(6):1222. https://doi.org/10.3390/nu11061222
3. Sangeeta S, Chandola G, Ramachandran P, Yadav P, Rai S. Fruits that heal: A natural boon to cure colon diseases. Annals of Phytomedicine. 2023;12(1):1-10. https://doi.org/10.54085/ap.2023.12.1.64
4. Banana exports from India to touch US$ 1 billion: APEDA: APEDA: Agri Exchange; 2024.
5. Singh M, Khan MI, Badruddeen JA, Ahmad M, Fatima G, Siddiqui Z, et al. GC-MS analysis of bioactive compounds, standardization and assessment of antimicrobial efficacy of Himalayan *Juniperus communis* L. stems. Annals of Phytomedicine. 2024;13(1):815-24. https://doi.org/10.54085/ap.2024.13.1.86
6. Malakar T, Hazarika D, Langthasa S. The screening of variety/varieties of strawberry suitable for assam condition. International Journal of Agricultural Science and Research. 9(4):199-208. https://doi.org/10.24247/ijasraug201926
7. Waghmare JS, Kurhade AH. GC-MS analysis of bioactive components from banana peel (*Musa sapientum*). European Journal of Experimental Biology. 2014;4(5):10-15.
8. Kawila A, ElSemlway S. The phytochemical composition, antimicrobial and in vitro cytotoxic activities of green and ripe banana pulps. Biological and Biomedical Journal. 2024;2(1):67-75. https://doi.org/10.21608/bbj.2023.242929.1008

9. Filimonov D, Lagunin A, Gloriozova T, Rudik A, Druzhilovskii D, Pogodin P, et al. Prediction of the biological activity spectra of organic compounds using the PASS online web resource. Chemistry of Heterocyclic Compounds. 2014;50:444-57. https://doi.org/10.1007/s10593-014-1496-1

10. Tomar V, Srivastava M. Comparative phytochemical estimation and free radical scavenging activity in leaves of *Cassia* sp. National Academy Science Letters. 2022;45(3):227-29. https://doi.org/10.1007/s40009-022-01111-z

11. Musini A, Rao MJP, Giri A. Phytochemical investigations and antibacterial activity of *Salacia oblonga* Wall ethanolic extract. Annals of Phytomedicine. 2013;2(1):102-27.

12. Afonso C, Julião D, Pinto E, Almeida A, Ferreira I, Bandarra N, et al. The effect of drying process on undervalued brown and red seaweed species: elemental composition. Journal of Applied Phycology. 2022;34(3):1749-61. https://doi.org/10.1007/s10811-022-0274-y

13. Ramezani S, Shekafandeh A. Influence of Zn and K sprays on fruit and pulp growth in olive (*Olea europaea* L. cv. 'Amygdalifolia'). Iran Agricultural Research. 2011:30(1 and 2):1-12.

14. Zekri M, Obreza TA. Micronutrient deficiencies in citrus: iron, zinc and manganese. University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences. 2003;1-3. https://doi.org/10.32473/edis-ss423-2003

15. Kakabra RF. Effect of seaweed, moringa leaf extract and biofertilizer on growth, yield and fruit quality of cucumber (*Cucumis sativus* L.) under greenhouse condition. arXiv preprint arXiv:240317984. 2024.

16. Yuniati N, Kusumiyati K, Mubarok S, Nurhadi B. The role of moringa leaf extract as a plant biostimulant in improving the quality of agricultural products. Plants. 2022;11(17):2186. https://doi.org/10.3390/plants11172186

17. Kumari PS, Ranjitha R, Vidhya N. Revitalizing property of banana peel extracts by antioxidant activity and antibacterial activity against acne causing *Staphylococcus epidermidis*. Annals of Phytomedicine. 2020;9(2):215-22. https://doi.org/10.21276/ap.2020.9.2.19

18. Reddy N, Priyanka AK, Raghavendra N. Isolation and characterization of triterpenoids from bark of *Syzygium alternifolium* (Wight) Walp. Annals of Phytomedicine. 2012;1(2):45-51.

19. Manju P, Pushpa A. Phytochemical analysis and in vitro free radical scavenging activity of rhizome of *Zingiber officinale* Rosc. Annals of Phytomedicine. 2020;9(2):257-62. https://doi.org/10.21276/ap.2020.9.2.24

20. Ansari NAIM, Ramly N, Faujan NH, Arifin N. Nutritional content and bioactive compounds of banana peel and its potential utilization: A review. Malaysian Journal of Science Health and Technology. 2023;9(1):74-86. https://doi.org/10.33102/mjosht.v9i1.313

21. Likittrakulwong W, Chanburee S, Kitpot T, Ninjiaranai P, Pongpamorn P. Phytochemical properties, *in vitro* antimicrobial and bioactive compounds of banana peel extractions using GC-MS. Natural and Life Sciences Communications. 2023;22(2):e2023021. https://doi.org/10.12982/NLSC.2023.021

22. Aina O, Amoo S, Mugivhisa LL, Olowoyo JO. Effect of organic and inorganic sources of nutrients on the bioactive compounds and antioxidant activity of tomato. Applied Ecology and Environmental Research. 2019;17(2). https://doi.org/10.15666/aeer/1702_36813694

23. Singh B, Singh JP, Kaur A, Singh N. Bioactive compounds in banana and their associated health benefits–A review. Food Chemistry. 2016;206:1-11. https://doi.org/10.1016/j.foodchem.2016.03.033

24. Sidhu JS, Zafar TA. Bioactive compounds in banana fruits and their health benefits. Food Quality and Safety. 2018;2(4):183-88. https://doi.org/10.1093/fqsafe/fyy019

25. Kumari P, Gaur SS, Tiwari RK. Banana and its by-products: A comprehensive review on its nutritional composition and pharmacological benefits. eFood. 2023;4(5):e110. https://doi.org/10.1002/efd2.110

26. Bansal Y, Sethi P, Bansal G. Coumarin: a potential nucleus for anti-inflammatory molecules. Medicinal Chemistry Research. 2013;22:3049-60. https://doi.org/10.1007/s00044-012-0321-6

27. Riveiro ME, De Kimpe N, Moglioni A, Vazquez R, Monczor F, Shayo C, et al. Coumarins: old compounds with novel promising therapeutic perspectives. Current Medicinal Chemistry. 2010;17(13):1325-38. https://doi.org/10.2174/092986710790936284

28. Venugopala KN, Rashmi V, Odhav B. Review on natural coumarin lead compounds for their pharmacological activity. BioMed Research International. 2013;2013(1):963248. https://doi.org/10.1155/2013/963248

29. El-Beltagi HS, Mohamed HI, Yousef HN, Fawzi EM. Biological activities of the doum palm (*Hyphaene thebaica* L.) extract and its bioactive components. Antioxidants in Foods and its Applications. 2018;49. https://doi.org/10.5772/intechopen.74772

30. Lemar KM. Cell death in the human pathogen *Candida albicans*: effects of garlic (*Allium sativum*) and garlic constituents allyl alcohol and diallyl disulphide: Cardiff University (United Kingdom); 2005.

31. Majewski M. *Allium sativum*: facts and myths regarding human health. Roczniki Państwowego Zakładu Higieny. 2014;65(1).

32. Şahin H. *In-vitro* anti-diabetic, anti-Alzheimer, anti-tyrosinase, antioxidant activities of selected coumarin and dihydroisocoumarin derivatives. International Journal of Secondary Metabolite. 2023;10(3):361-69. https://doi.org/10.21448/ijsm.1196712

33. Balbuena-Rebolledo I, Rivera-Antonio AM, Sixto-López Y, Correa -Basurto J, Rosales-Hernández MC, Mendieta-Wejebe JE, et al. Dihydropyrazole-carbohydrazide derivatives with dual activity as antioxidant and anti-proliferative drugs on breast cancer targeting the HDAC6. Pharmaceuticals. 2022;15(6):690. https://doi.org/10.3390/ph15060690

34. Orabi EA, Orabi MA, Mahross MH, Abdel-Hakim M. Computational investigation of the structure and antioxidant activity of some pyrazole and pyrazolone derivatives. Journal of Saudi Chemical Society. 2018;22(6):705-14. https://doi.org/10.1016/j.jscs.2017.12.003

35. Zhao Z, Dai X, Li C, Wang X, Tian J, Feng Y, et al. Pyrazolone structural motif in medicinal chemistry: Retrospect and prospect. European Journal of Medicinal Chemistry. 2020;186:111893. https://doi.org/10.1016/j.ejmech.2019.111893

36. Vega-Pérez JM, Periñán I, Argandoña M, Vega-Holm M, Palo-Nieto C, Burgos-Morón E, et al. Isoprenyl-thiourea and urea derivatives as new farnesyl diphosphate analogues: Synthesis and *in vitro* antimicrobial and cytotoxic activities. European Journal of Medicinal Chemistry. 2012;58:591-612. https://doi.org/10.1016/j.ejmech.2012.10.042

37. McMorris TC, Chimmani R, Alisala K, Staake MD, Banda G, Kelner MJ. Structure− activity studies of urea, carbamate and sulfonamide derivatives of acylfulvene. Journal of Medicinal Chemistry. 2010;53(3):1109-16. https://doi.org/10.1021/jm901384s

38. Prattes M, Grishkovskaya I, Hodirnau V-V, Rössler I, Klein I, Hetzmannseder C, et al. Structural basis for inhibition of the AAA-ATPase Drg1 by diazaborine. Nature Communications. 2021;12(1):3483. https://doi.org/10.1038/s41467-021-23854-x

39. António JoP, Gonçalves LM, Guedes RC, Moreira R, Gois PM. Diazaborines as new inhibitors of human neutrophil elastase.

ACS Omega. 2018;3(7):7418-23. https://doi.org/10.1021/acsomega.8b00702

40. Yu X, Zhao M, Liu F, Zeng S, Hu J. Identification of 2, 3-dihydro-3, 5-dihydroxy-6-methyl-4H-pyran-4-one as a strong antioxidant in glucose–histidine Maillard reaction products. Food Research International. 2013;51(1):397-403. https://doi.org/10.1016/j.foodres.2012.12.044
41. Adeloye AO, Ajibade PA. Synthesis and characterization of a Ru (II) complex with functionalized phenanthroline ligands having single-double linked anthracenyl and 1-methoxy-1-buten-3-yne moieties. Molecules. 2010;15(11):7570-81. https://doi.org/10.3390/molecules15117570
42. Guo L, Wu J-z, Han T, Cao T, Rahman K, Qin L-p. Chemical composition, antifungal and antitumor properties of ether extracts of *Scapania verrucosa* Heeg. and its endophytic fungus *Chaetomium fusiforme*. Molecules. 2008;13(9):2114-25. https://doi.org/10.3390/molecules13092114
43. Kaur M, Singh M, Chadha N, Silakari O. Oxindole: A chemical prism carrying plethora of therapeutic benefits. European Journal of Medicinal Chemistry. 2016;123:858-94. https://doi.org/10.1016/j.ejmech.2016.08.011
44. Khan I, Ibrar A, Abbas N. Oxadiazoles as privileged motifs for promising anticancer leads: Recent advances and future prospects. Archiv der Pharmazie. 2014;347(1):1-20. https://doi.org/10.1002/ardp.201300231
45. Yanase M, Funabashi M. Stereoselective 1, 2-cis-1-thioglycosidation of aldohexoses with tert-butyl mercaptan in 90 % trifluoroacetic acid. Journal of Carbohydrate Chemistry. 2000:19(1):53-66. https://doi.org/10.1080/07328300008544064
46. Bhalla N, Ingle N, Patri SV, Haranath D. Phytochemical analysis of *Moringa oleifera* leaves extracts by GC-MS and free radical scavenging potency for industrial applications. Saudi Journal of Biological Sciences. 2021;28(12):6915-28. https://doi.org/10.1016/j.sjbs.2021.07.075
47. Anonymous. CAMEO Chemicals. 2024.
48. Misra D, Ghosh NN, Mandal M, Mandal V, Baildya N, Mandal S, et al. Anti-enteric efficacy and mode of action of tridecanoic acid methyl ester isolated from *Monochoria hastata* (L.) Solms leaf. Brazilian Journal of Microbiology. 2022;53(2):715-26. https://doi.org/10.1007/s42770-022-00696-3
49. Baumann LS. Cosmeceuticals and cosmetic ingredients. McGraw Hill Professional; 2014.
50. Patti A, Lecocq H, Serghei A, Acierno D, Cassagnau P. The universal usefulness of stearic acid as surface modifier: applications to the polymer formulations and composite processing. Journal of Industrial and Engineering Chemistry. 2021;96:1-33. https://doi.org/10.1016/j.jiec.2021.01.024
51. Abdelaziz R, Elsheshtawy HM, El-Houseiny W, Aloufi AS, Alwutayd KM, Mansour AT, et al. A novel metabolite of *Streptomyces coeruleorubidus* exhibits antibacterial activity against *Streptococcus agalactiae* through modulation of physiological performance, inflammatory cytokines, apoptosis and oxidative stress-correlated gene expressions in Nile tilapia (*Oreochromis niloticus*). Fish and Shellfish Immunology. 2024;148:109496. https://doi.org/10.1016/j.fsi.2024.109496
52. Lingfa L, Tirumala A, Ankanagari S. GC-MS profiling of anticancer and antimicrobial phytochemicals in the vegetative leaf, root and stem of *Withania somnifera* (L.) Dunal. International