Bioactive Innovation and Technology

Improving Crop Productivity and Farm Income

PMPD

Potassium Meta Phosphate Dimer

World First

Bioactive P and K Nutrient

For Sustainable Agriculture

To Improve Climate Resilience

Editor

Prashant P. Nandargikar

PMPD

Improves Agricultural World for Everyone

Boost the Grower Farmers Income Over 60%

PMPD Increases Crop Yield and Improves Produce Quality

Reduces Use of Plant Protection Chemicals and Fertilizer

Supports and Compliments Organic & Conventional Farming

ISHA AGRO

Strategic Agricultural Partner

About Book

The book highights the invention of PMPD, purpose and potential, likely mode of action and its possible role in plant metabolisms. PMPD application by the farmers in various crops will definitely help to improve the farmer's income. In this manual, the concept of PMPD is explained in a simple and lucid language. However, technical narration at certain places is inevitable. It is a matter of great pride for all the scientists, who under the visionary guidance of late Dr. N.R. Iyyangar, Director, NCL-CSIR, Pune, invented PMPD molecule for the larger benefits of farming community. Thus, it goes without saying that we are the pioneers of introducing PMPD technology in India. PMPD technology has been field tested by various Agricultural Research Institutions and also on the farmer's fields across different locations in India. PMPD technology plays a vital role in increasing crop productivity, reducing cost of cultivation and improving produce quality by retaining its inherent nutritional values. This technology also reduces the chemical load on crop plants, thereby reducing soil nutrient depletion rate and offering safety to the consumers with reduction in pesticide applications.

We are indebted to all our fellow-scientists, who not only extended their unstinted cooperation throughout the process of invention of the PMPD molecule, but also toiled hard for achieving this goal by maintaining team spirit. Invention of PMPD molecule is an outcome of untiring efforts, patience & perseverance of our scientists, who have proved that there is no limit to what one can achieve with sincere and directed efforts. We are humble in our efforts, but proud of our achievement.

It is often said that "no human being is infallible" and we also do not claim to be an exception to this Gospel Truth. We shall, therefore, be glad to receive any useful suggestions from our esteemed readers and users, which will help us carry out further improvement in our approach.

Team - Isha Agro

ISHA AGRO
Strategic Agricultural Partner

We thank the members of editorial board for their valuable suggestions while compiling the data on technology. Your inputs will certainly provide a platform for researcher to carry their studies on innovation in many ways. We are committed for farmers welfare and have no commercial interest whatsoever while sharing as well as presenting the information on PMPD Bio - activity Innovation and Technology.

Preface

The world's population is increasing rapidly day by day and would demand more food from the limited natural resources such as land and water. Keeping in view the need of 7 billion people worldwide, agricultural productivity will have to be increased substantially by using available resources, which are being depleted rapidly. Thus, to fulfil the basic needs of present and future is a more challenging task for farming communities and agricultural technologists.

Over the years agricultural scientists have developed various crop varieties and production technologies. Agricultural development organizations and funding agencies are doing their best to improve yield and quality of agricultural produce. All these efforts seem inadequate looking to the ever increasing population.

Nutrients play an important major role in crop production. Phosphorus (P) plays a major role in metabolic processes and Potash (K) is important for inducing ability to tolerate various biotic and abiotic stresses. Conventionally, these major crop nutrients are made available through chemical fertilizers in the soil. However, 80% of phosphate gets fixed in soil and only 20% are absorbed by the crop plants. K is given in an ionic form, whereas, its associated cation has a role that is not synergetic with the given potash (K).

To overcome these constraints of phosphorus and potash, we have invented PMPD (Potassium Meta Phosphate Dimer) by using catalytic technology. The technical molecule of PMPD is 180% water soluble and quickly gets absorbed by green foliage.

Besides its vital role in plant metabolism, PMPD induces the abiotic and biotic stress tolerance. Hence, the crop yield and quality improves to the best of its genetic potential even under the stressful conditions. Application of PMPD increases plant productivity from 15% to 50% with remarkable improvement in quality along with reduction in the cost of cultivation. The inclusion of PMPD can certainly boost the economy of farmers and earn substantial profits in farming. PMPD thus, is a molecule of choice for improving farmer's income by optimizing the use of our natural resources.

We attempt here to present PMPD technology to the interested researchers in all the areas of plant sciences. As a result of climate change it is expected that stress in many combinations such as abiotic + abiotic, abiotic + biotic, or biotic + biotic is going to affect the crop performance adversely. Application of PMPD will be an integral part of sustainable agriculture under changing climate scenario of future combinational stress. We trust that information given in this book will be useful in building strategies to encounter the biotic and abiotic stress in crop plants.

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Editorial Board

Charudatta D Mayee, Chairman of the Board of Directors of AFC, holds a Doctorate degree from Indian Agricultural Research Institute (IARI), New Delhi and Post Doctoral from University of Hohenheim, Stuttgart (Germany). He did his Post Doctoral, Alexander von Humbolt Fellow from University of Hohenheim, Stuttgart (Germany) and also holds membership of many scientific committees.

Dr. Mayee served as the Chairman of Indian Agricultural Scientists Recruitment Board (ASRB) and also as Agricultural Commissioner in the Ministry of Agriculture & ; Farmers' Welfare, Govt of India. Prior to this, he also had a stint as Director of ICAR's Central Institute of Cotton Research (CICR), Nagpur and Vice Chancellor of Vasantrao Naik Marathwada Krushi Vidyapeeth (VNMKV), Parbhani.

Dr. C. D. Mayee is a renowned Cotton Scientist currently serving as President of South Asia Biotechnology Centre (SABC) and Vice President of the National Academy of Agricultural Sciences (NAAS), New Delhi. He has done extensive research in Plant Pathology, Epidemiology and Management, Human Resource Development, Cotton Improvement and Biotechnology. He was a Member of African Biosafety Network Expertise, Burkina Faso and International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

Dr. R. M. Naik served at the Department of Biochemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri for 35 years. He retired as Professor & Head of the Department in 2021. He obtained his Ph.D. degree in Biochemistry from Indian Agriculture Research Institute , New Delhi in 1996. He was awarded Biotechnology Overseas Associateship from DBT, Govt. of India for his Post doctoral Research at Institute of Plant Biotechnology, University of Paris, France during 2003. His specialization areas were plant mitochondrial metabolism in relation to nitrate assimilation, molecular marker assisted breeding for disease resistance, biochemical & molecular changes in crop plants due to abiotic / biotic stresses. He analysed the differences in C3 and C4 plants and CMS II mutant by carbon monoxide sensitivity of cytochrome oxidase technique. He has published more than 100 research publications in peer reviewed journals and was member of review committee of some journals. He contributed in development of YVMV resistant okra variety, virus resistant Papaya and smut resistant sugarcane varieties.

Editorial Board

Sushil Solomon received his doctorate degree from Punjab Agricultural University, Ludhiana (India), and joined Agricultural Research Service of Indian Council of Agricultural Research (ICAR-Ministry of Agriculture) in 1977. As a director of the Indian Institute of Sugarcane Research, Lucknow, he was actively involved in the development and transfer of relevant technologies to the sugarcane farmers and industry for their sustainable development. During his 36 years of research career, he has published over 120 research papers, 22 books and many technical reports for the benefit of global sugar industry. Dr. Solomon is the president of Society for Sugar Research and Promotion and vice-president of the International Association of Professionals in Sugar and Integrated Industries (IAPSIT) and on the advisory bodies of many national and international apex organizations. As an advisor, he has visited Brazil, Australia, China, Vietnam, Egypt, Iran, Sri Lanka, Cuba, Thailand, etc. He is an Editor-in-Chief of an international Sugar Tech journal, published by Springer and has also organized many international conferences. The Government of China bestowed on him the most prestigious honor "Friendship Award" in 2005 in view of his active role in promoting collaboration and partnership among sugar producing countries. Besides, he is a recipient of many international honors and awards, including Award of Excellence: IAPSIT (2006), Sinai University Peace Award Al: Arish University, Egypt (2008), Global Award of Excellence: IAPSIT (2008), Indira Gandhi Award (2013), Noel Deerr Gold Medal STAI (2014, 2016), and Leadership Excellence Award (2018) from Thailand Society of Sugarcane and Sugar Technologists. Dr. Solomon was appointed Vice Chancellor of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, for a period of three years in Dec. 2016, a premier agricultural university in North India.

S. N. Sushil

Director National Bureau of Agricultural Insect Resources (NBAIR), formerly National Bureau of Agriculturally. Important Insects (NBAII) is located in Bangalore, Hebbal, India.

Field of Specialization: Agricultural Entomology, Biological Control, IPM, Biosystematics, Apiculture, Plant Protection Regulations and Policies. Publications: Total: 335, Research papers : 82 Paper presented in symposium/ seminars (Abstracts): 36 Books: 11, Popular articles: 14

Editorial Board

Yang Rui Li (life time professor) graduated and earned B.A. degree in the Department of Agronomy, Guangxi Agricultural University, China in January 1982 and M.S. and Ph.D. degrees in the Department of Agronomy, Fujian Agricultural University, in July 1985 and January 1988, respectively. He was employed as a lecturer in the Department of Agronomy, Guangxi Agricultural University, from January 1988 to December 1989, associate professor (from March, 1991 to November 1992) and professor (since December, 1992) in the Department of Agronomy, Guangxi Agricultural University, vice president of Guangxi University from April, 1997 to April, 1998, and president of Guangxi Academy of Agricultural Sciences from May, 1998 to November, 2012. He has been serving as the director of Sugarcane Research Centre, Chinese Academy of Agricultural Sciences, since September, 2007 and chief expert of the National Joint Research Program for Elite Sugarcane Variety Development in China since 2018. He is the president of International Association for Leadership Professionals of Sugar and Integrated Technologies (IAPSIT), vice-president of Society for Sugar Research and Promotion (SSRP), and president of Chinese Sugarcane Industry Association for Technological Innovation (CSIATI). He has published 13 books and more than 1000 research publications & received 22 scientific research achievement awards from Chinese Government todate and 14 awards from international organizations, including Lifetime Achieve- ment Award: SSRP (2011), Lifetime Achievement Award: IAPSIT (2014) and Leadership Excellence Award from Thailand Society of Sugarcane and Sugar Technologists (2018).

Nguyen Bao Quoc Research Institute for Biotechnology and Environment, Nong Lam University, HCMC, Vietnam. Nguyen Bao Quoc has completed his PhD in the field of biological and environmental sciences at Kobe University, Japan in 2008 and then spent four years as JSPS postdoctoral fellow and research associate in Kobe University, Japan and Dartmouth College in USA. He is presently a lecturer at the Research Institute for Biotechnology and Environment, Nong Lam University, HCMC, Vietnam. He has published more than ten papers in reputed journals, book chapter and has been serving as reviewers for many international and national journals.

Editorial Board

Vishnu D. Rajput is working as an Associate Professor (leading researcher), head of “Soil Heal” laboratory at Sothern Federal University, Russia. His ongoing research is based on soil contaminations, i.e., potentially toxic elements and metallic nanoparticles and investigating the bioaccumulation, bio/geo-transformations, uptake, translocation, and toxic effects of NPs on plant physiology, morphology, anatomy, the ultrastructure of cellular and subcellular organelles, cytomorphometric modifications and DNA damage. He comprehensively detailed the state of research in environmental science in regard to “how nanoparticles/heavy metals interact with plants, soil, microbial community and the larger environment.” He has published (total of 346 scientific publications) 201 peer reviewed highly rated full length articles, 18 books, 70 chapters (Scopus indexed), and 44 conference articles. He is an internationally recognized reviewer (peer reviewed 208 manuscripts for internationally reputed journals) and received an outstanding reviewing certificate by Elsevier and Springer. He is an editorial board member of various high impacted journals.

Amaresh Chandra

DBT CREST Fellow at USDA-ARS, SRU, LA, USA, Principal Scientist at IISR Lucknow, Uttar Pradesh, India. Principal Scientist and Head (Presently at USDA-ARS, SRU, Louisiana, USA) April 2009. Head, Department of Plant Physiology and Biochemistry and Research on Sugarcane Genomics and Molecular Biochemistry CSIRO, Brisbane, Australia. Developed genetic linkage map of Stylosanthes scabra and progenitors studyusing STS markers JNU, New Delhi, India. Ph.D. Scholar and completed Ph.D on cloning and characterization of CaMgenes in A. thaliana Education Department of Biochemistry, BHU, Varanasi. M.Sc., Biochemistry · (1983 - 1985) BHU, Varanasi B.Sc. (Hons), Botany, Zoology and Chemistry (Hons) · (1980 - 1983) Sakaladiha Bazar, Chandauli.

Editorial Board

Govind P. Rao is working as Director, Institute of Agriculture and Natural Sciences, DDU Gorakhpur University, Gorakhpur, India. Earlier, he retired as principal scientist (plant pathology) at Indian Agricultural Research Institute, New Delhi, India in January 2022. He obtained his Ph.D. degree in botany (plant virology) from Gorakhpur University, India, in 1986. He did Post Doctorate at the University of Urbana, Champaign, Illinois, USA, with Prof. R.E. Ford in 1994 on sugarcane and maize viruses. Dr. Rao has 33 years of research experience in plant pathology, especially on plant virology and phytoplasmas. He did significant contributions in characterization of plant viruses and phytoplasmas infecting sugarcane, vegetables, ornamentals, fruits, wheat, maize, cucurbits, maize, and sorghum. He has published over 200 research publications and authored and edited nearly 10 textbooks and 16 edited books to his credit. He has been awarded several prestigious national and international awards to his credit. Dr. Rao has been presidents, secretary general, and secretary of various renowned academic societies of India and abroad. He has also been elected as fellows of several academic societies in India and abroad. He is also editor in chief of Sugar Tech journal, published from Springer-Nature. Besides, Dr. Rao has visited over 30 countries as visiting scientists, for invited talk, postdoc fellow, research training, panel discussion, and for attending workshops and conferences.

Krishan K. Verma is working as Foreign Expert at Sugarcane Research Institute, Chinese Academy of Agricultural Sciences and Guangxi Academy of Agri- cultural Sciences, Nanning, Guangxi, China. His research focuses on environmental toxicology, bioengineering modelling, plant physiology, molecular biology, their impacts on growth, physiological and molecular adaptation strategies of plants to stress- ful environment, and how they affect the plant structure. He has published more than 78 scientific research articles/reviews, ten books, and ten book chapters. He is an internationally recognized reviewer. He has been serving as an editorial board member of various peer reviewed journals.

Editorial Board

Xiu-Peng Song is working as Associate Professor at Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences, Nanning, Guangxi, China. His ongoing research focuses on physiology and biochemistry of stress resistance, occurrence mechanisms and comprehensive control of diseases and insect pests in sugarcane crop. He received his master's and doctorate (biochemistry and molecular biology) degrees from Guangxi University, Nanning, Guangxi, China. He presided over four scientific research projects such as the National Natural Science Foundation China and participated in 12 national/international cooperation projects. He has also received five prestigious awards, such as Guangxi Science and Technology Progress Award. He has published more than 50 scientific publications.

Raffaella Rossetto is graduated in Agronomic Engineering from Luiz de Queiróz College of Agriculture (1981), Master's in Nuclear Energy in Agriculture from the Luiz de Queiróz College of Agriculture (1987) and Ph.D. in Soils and Plant Nutrition from the Luiz de Queiróz College of Agriculture (1994). Between 2011 and 2012 she did a Post Doctorate at the University of Florida, EREC campus in Belle Glade, where she worked with crop options for bioenergy. She is currently a Scientific Researcher at Instituto Agronomico de Campinas-IAC, developing research activities with the Sugarcane program in Jau, SP. Has experience in Agronomy, with an emphasis on Soil Fertility and Fertilization, Use of Waste in the cultivation of sugarcane and environmental issues, acting on the following topics: sugarcane, fertilization, mineral nutrition, chemical attributes, soil and environment quality , nitrogen dynamics. The most relevant research projects were on: Use of vinasse in sugarcane and environmental aspects (UNICA, IAC, FAPESP), Nitrogen fertilization in sugarcane ratoons - N2 losses in protected fertilizers (SABIC, UBYFOL, FUNDAG), Liming for sugarcane culture in acid soils (Massari Ltd, FUNDAG). Nutrition and irrigation for sugarcane (Us. Sao Martinho, Us. Denusa, FUNDAG). She has been internationally a part of the ISSCT-International Society of Sugarcane Technologists, representing Brazil on the Technical Committee, and IAPSIT-International Association of Professionals in Sugar and Integrated Technologies, representing Brazil on the Executive Committee. In Brazil, since 1998 she has been elected Treasure Secretary of STAB - Brazilian Society of Sugar and Ethanol Tecnhologist. She received three awards for her work in the sugarcane sector. (Source: Lattes Curriculum)

Acknowledgment

We thank all the Hon'ble Vice Chancellor of Agriculture Universities, Technologists & Administrators involved in research and development activities, Scientists, Researchers, Directors of Research of Institutes, for sparing their valuable time to discuss and understand the impressive effects of PMPD (Potassium Meta Phosphate Dimer) on various crops. The discussions were very fruitful while exploring the various facets of application of PMPD to different crops including sugarcane.

The research trials of PMPD (PSAP-ProPhite) conducted at various institutions and on farm demonstrations under the guidance of an eminent scientists helped us in studying the impact of PMPD on yield and quality of farm produce.

Even the guidance of staff from Cane Department of sugar mills helped us immensely while understanding the mode of action of PMPD and its performance under various soils and agro-climatic conditions under which sugarcane is grown. We are very grateful to all the staff for their guidance, support and technical help.

It is incredible that PMPD is absorbed quickly through foliage and does not have any residual effect on the plant or soil as compared to other fertilizer sources of elemental ‘P’ and ‘K’. Besides, the quantum requirement of ‘phosphorus’ and ‘potash’ supplied through PMPD is very less compared to those applied on larger quantity through conventional fertilizer sources.

In the process of evaluation of PMPD, we received very valuable guidance from senior technologists and innovative progressive farmers who readily volunteered for conducting on farm demonstrations cum research trials.

The management of some progressive sugar industries also readily supported our humble efforts and cooperated in conducting cane productivity and quality evaluation in their area of operation. Without their support, we would not have come to the conclusion that PMPD improves cane yield by 15% - 50% and sugar recovery from 0.3 to 1.0 unit.

“Active Phosphorus” and “Potash” of PMPD are one of its kinds in the world of chemistry. Those who have seen and experienced the performance of PMPD on the field are of unanimous opinion that, "PMPD molecule will help to witness another green revolution in India and PMPD will turn around agriculture across the globe ".

We are very sincerely thankful to all those who helped us in evaluating this wonderful revolutionary molecule. During the discussions, they shared some positive insights on PMPD with different prospective.

Ultimately, it is concluded that PMPD technology helps to alleviates Biotic and Abiotic stress in crop plants and PMPD has potential to transform agriculture.

Team - ISHA

Felicitation

"Pune Agritech Summit" organized by Navbharat Newspaper
Group on 21 April 2018 College of Agriculture Pune, India

Left to Right :

Mrs. Snehlata Bipin Kolhe, Hon'ble MLA, Kopargaon, Ahmednagar, M. S. India

Mr. Anil Shirole, Hon'ble Member of Parliament, Govt. of India

Mr. Prashant Nandargikar, Inventor of PMPD, Pune, India

Mr. Subhash Deshmukh, Hon'ble Minister for Co-Operation, Marketing & Textiles, Govt. of Maharashtra

Mr. Radha Mohan Singh Ji, Hon'ble Minister for Agriculture & Farmers Welfare, Govt. of India

Mr. Sadabhau Khot, Hon'ble Agriculture Minister for State Govt. of Maharashtra, India

INTERNATIONAL CONFERENCE SUGARCON - 2019
February 16-19-2019

Left to Right :

Prof. Yang Rui Li-Vice President SSRP Nanning P. R. China

Dr. S. Soloman - Former Vice Chancellor, CSAAU Kanpur, India

Shri. Surya Pratap Sahai Ji - Hon'ble Minister of Agriculture, Govt. of Uttar Pradesh, India

Shri. Ganga Singh Kushwaha Ji - Hon'ble MLA Fazilnagar, Uttar Pradesh, India

Mr. Prashant P. Nandargikar, Inventor of PMPD, Pune, India

Felicitation

National Workshop on PSAP, 17 th August 2022 held
at A.P. Shinde Auditorium, New Delhi, India

Right to Left :
Dr. C. D.Mayee - Professor, M. S. India
Mr. Prashant P. Nandargikar, Inventor of PMPD, Pune, India
Shri. Parshottam Rupala Ji, Hon'ble Minister of Fisheries, Animal Husbandry and Dairying, Govt. of India
Shri. Kailash Choudhary Ji, Hon'ble Minister of State for Agriculture and Farmers Welfare, Govt. of India
Mrs. Medha Nandargikar, Director, Isha Agro Sciences Pvt. Ltd., Pune, India
Dr. Narendra Mohan, Director, National Sugar Institute, Kanpur, Uttar Pradesh, India

INTERNATIONAL CONFERENCE SUGARCON - 2019
February 16 - 19 - 2019

Left to Right :
Mr. R.L. Tamak E.D. DSCL Group, India
Dr. S Solomon Former Vice Chancellor-CSAAU Kanpur, Uttar Pradesh, India
Dr. A. K. Singh Dy. Director General, Horticulture, Govt. of India
Mr. Prashant P. Nandargikar, Inventor of PMPD, Pune, India
Dr. Yang Rui Li Vice President, SSRP, Nanning .P.R China
Dr. Bakshi Ram Yadav - Director, SBI, Coimbatore, T.N. India

FCO Registeration

The Fertiliser
(Inorganic, Organic or Mixed)
(Control) Order 1985

(As amended upto March 2023)

FAI
ENSURING FOOD SECURITY

THE FERTILISER ASSOCIATION OF INDIA
NEW DELHI

4.	**Potassium Magnesium Sulphate**	
(i)	Moisture per cent by weight maximum	0.5
(ii)	Water soluble potassium (as K_2O) per cent by weight, minimum	22.0
(iii)	Magnesium as MgO per cent by weight, minimum	18.0
(iv)	Sulphate Sulphur (as S) per cent by weight, minimum	20.0
(v)	Total chloride(as Cl) per cent by weight,maximum	2.5
(vi)	Sodium (as NaCl), per cent by weight, maximum	2.0
5.	**Mono Ammonium Phosphate 12:61:0 (100% water soluble)**	
(i)	Moisture per cent by weight, maximum	0.5
(ii)	Ammoniacal nitrogen per cent by weight, minimum	12.0
(iii)	Water soluble phosphorous(as P_2O_5) per cent by weight, minimum	61.0
(iv)	Sodium as NaCl per cent by weight, maximum	0.5
(v)	Matter insoluble in water per cent by weight,maximum	0.5
6.	**Urea Phosphate 17:44:0 (100% Water Soluble)**	
(i)	Moisture per cent by weight, maximum	0.5
(ii)	Total nitrogen (all in urea form)per cent by weight, minimum	13.0
(iii)	Water soluble phosphorous (as P_2O_5)per cent by weight,minimum	44.0
(iv)	Matter insoluble in water per cent by weight, maximum	0.5
7.	**Potassium Nitrate (prilled) (13-0-45) (soil application)**	
(i)	Moisture per cent by weight, maximum	0.5
(ii)	Total nitrogen (all in Nitrate form) per cent by weight, minimum	13.0
(iii)	Water soluble potassium (as K_2O) per cent by weight, minimum	45.0
(iv)	Sodium (as Na) per cent by weight, maximum	1.0
(v)	Total chloride(as Cl) per cent by weight, maximum	1.5
(vi)	Matter insoluble in water, per cent by weight, maximum	1.5
(vii)	Particle size- 80 per cent of the material shall be retained between 1 mm and 2.8 mm IS sieve.	
8.	**24-24-0 (100% Water Soluble Complex Fertiliser)**	
(i)	Moisure per cent by weight, maximum	0.5
(ii)	Total nitrogen (Ammonical and Nitrate), minimum	24.0
(iii)	Ammonical Nitrogen per cent by weight, minimum	14.0
(iv)	Nitrate Nitrogen per cent by weight, minimum	10.0
(v)	Water Soluble Phosphorus per cent by weight, minimum	24.0
(vi)	Matter insoluble in water per cent by weight, maximum	0.5
***9.**	**Potassium Metaphosphate dimer (0-40-40)**	
(i)	Moisture per cent by weight, maximum	0.5
(ii)	Water soluble phosphorus (as P_2O_5) per cent by weight, minimum	40.0
(iii)	Water soluble Potassium (as K_2O) per cent by weight, minimum	40.0
(iv)	Matter insoluble per cent by weight maximum	0.5
(v)	Lead as Pb per cent by weight maximum	0.0003
(vi)	Cadmium (as Cd) per cent by weight, minimum	0.0025
(vii)	Arsenic(as As) per cent by weight, maximum	0.1
	1(j) Beneficial Element Fertiliser	
1.	**Ortho Silicic Acid (OSA) 2.0% WSL**	
(i)	Ortho Silicic $\{Si(OH)_4\}$, per cent by weight, minimum	2.0
	Plant available Silicon (Si) equivalent, per cent by weight minimum	0.6
(ii)	*Omitted	

*Vide S.O. 4477 (E) dt. 22.09.2022

PSAP-ProPhite Organic Certification

STATEMENT OF COMPLIANCE

NPOP
ISAW
2026

NCCA

Name of Production Unit	Brand Name	Category of the product (Microbial preparations/herbal preparations/bio-organic preparations/manure)	Use for nutrient/pest control/growth enhancement	List of ingredients		Estimated Quantity (in MT)	Shelf life of the Product (in Months)
Integrated Fertilizers & Chemicals Company Pvt. Ltd. (IFCCO Pvt. Ltd.)	ProPhite	Bio-Fertilizer	growth enhancement	Ingredient Name(s)	Percentage Used	1,10,000	24
				PSAP	90.00000		
				Zinc Sulphate	5.00000		
				Manganese Sulphate	5.00000		
				Boron	0.00000		
				Ammonium Molybdate	1.00000		
				Molybdenum	5.00000		
Integrated Fertilizers & Chemicals Company Pvt. Ltd. (IFCCO Pvt. Ltd.)	PSAP	Bio-Fertilizer	growth enhancement	Ingredient Name(s)	Percentage Used	1,20,000	24
				PSAP	90.00000		
				Zinc Sulphate	5.00000		
				Manganese Sulphate	5.00000		
				Boron	0.05000		
				Ammonium Molybdate	0.05000		
				Molybdenum	5.00000		

PMPD Bioactive Innovation and Technology

Key Features

- PSAP–ProPhite are trade mark of PMPD, tested by Institutes and used by the farmers.
- PMPD (Potassium Meta Phosphat Dimer) World's first bioactive 'P' and 'K' nutrient.
- Increases crop yield by 15-50% under stress and reduces PP & Fertilizer use by 50%.
- Improves farmer's income over 60% and substitutes import of Oil, Fuel & Fertilizer.
- Two lakh farmers are using PSAP and it is getting popularized amongst the Farming community.
- PMPD is an indispensable component of exports as it reduces the residue problems.
- PMPD supports Organic, Conventional and Natural farming by retaining the soil health.
- Five times more efficient in feeding P-K than fertilizer save non renewable resources.
- PMPD is notified as 00:40:40 revolutionary grade improving agriculture for everyone.

Phosphorus and Its Role

Three forms of Phosphorus are applied to crop plants

1. **Nutrient based phosphorus: in phosphate form: PO_4^-**

   Phosphates are applied to crop plants as a source of nutrient. In the form of chemical fertilizers such as super phosphate, 00-52-34, 10-26-26, DAP (diammonium phosphate) (12-61), 19-19-19 as well as from organic matter. Solubility, fixation, leaching, availability and uptake are the problems associated with phosphorus and potash-based fertilizers. Even after spraying, these fertilizers are very poorly absorbed by foliage of majority crop plants and if remained on plant, the residue supports fungal growth. Hence managing PO_4^- in the field conditions is very difficult.

2. **Fungicide-based phosphorus: in phosphite form: PO_3^-**

   Mono and di potassium salt of phosphorous acid and/or potassium salt of phosphonic acid or potassium phosphite, are some of the name of the molecule. They are normally applied by growers in combination with some fungicides such as captan, mancozeb. For pH correction of these fungicides as well as PO_3^- molecule has been reported in various references to have some specified role in management of diseases caused by oomycetes. However, it is phytotoxic if applied in excess. Carbon - Phosphite molecules are phosphonates also refer as PGR or fungicides like fosetly-Al and N-(phosphonomethyl) glycine herbicide.

3. **Stress-alleviator-based phosphorus: in Meta Phosphate Dimer form : $P_2O_6^-$**

   PMPD is an autonomous form of phosphorus that plays a major role in biosynthesis of primary and secondary metabolites including SAP (shikimic acid pathway). It overcomes the limitation of phosphate and phosphites molecules in its application to crop plants. Application of PMPD along with fertilizers creates a synergetic effect. PMPD supports generation, storage and translocation of bio-energy in ATP/NADP bonds. The availability of ATP and a reductant in the form of NADPH helps the plants to scavange ROS and adapt to stress. Hence, recovery of various metabolic processes from stress in PMPD-treated plants is very fast and effective. Active phosphorus alleviates abiotic and biotic stress in crop plants.

Bio-active phosphorus is identified and authenticated as stress alleviator when applied with potash.

Phosphorus and Its Role

Three forms of Phosphorus are applied to crop plants

PMPD: Autonomous Combination of Phosphorus and Potash

Plants frequently cope with rapidly fluctuating and adverse environmental conditions because of their intrinsic metabolic capabilities. Variations in the outside environment could put the plant metabolism out of homeostasis and make it necessary for the plant to harbour some advanced genetic and metabolic mechanisms within its cellular system. Plants possess an array of protective mechanisms acquired during the course of evolution to combat adverse environmental situations. Such mechanisms cause metabolic re-programming in cells to facilitate routine physico-biochemical processes irrespective of the external situations. Without phosphorus in the environment no living organisms could exist. Phosphorus is present in all plant and animal tissue. It is necessary for such life processes as photosynthesis, the synthesis and breakdown of carbohydrates, and the transfer of energy within the plant. Phosphorus is taken up by the plant from the soil. Unless the soil contains adequate phosphorus or it is supplied to the soil from external sources, plant growth will be limited. Phosphorus does not occur as abundantly in soils as does the other major nutrients, nitrogen and potassium. Phosphorus occurs in both inorganic and organic forms in the soil. Small fraction of the total phosphorus is in a form available to plants.

	Nutrient-based phosphorus (PO_4^-)	Fungicide-based phosphorus (PO_3^-)	Stress Alleviator-based phosphorus ($P_2O_6^-$)
Base	a. Phosphate : PO_4^- Synthetic fertilizer base b. Organic Phosphorus	a. Alkali metal salts fungicide base b. Carbon compound growth regulator base	Molecular combination of active phosphorus and potash catalytic base
Function	Phosphorus is a major plant nutrient that induces virtually all the biochemical processes and development phases of crop plants.	These products have fungicistic mode of action and / or regulate some metabolisms. However PO_4^- and PO_3^- phosphorus share antagonistic relationship. Hence do not replace each other.	Phosphorus in active form has important role in stress alleviation. Role of active phosphorus is complementary and supplementary to nutrient base phosphorus PO_4^-. Phosphorus and potash from PSAP get rapidly absorb and quickly translocated in crop plants.
Limition	**Synthetic fertilizers** • Solubility • Fixation/Leaching • Uptake • Absorption • Availability • Soil and water pollution **Organic phosphorus** • Very slowly available • Inadequately available • Soil bacterias are required • Poor source of phosphorus	**Alkali metal salts** • Crop wise specific application • Phytotoxic • No direct role in growth • PO_3^- unsuited in ATP generation **Carbon compounds** • Some compounds have MRL • May hinder growth metabolism • Debate is going on towards its environment-friendly utilization	Can be applied at any given stage as well as condition of crop plants. More effective under abiotic stresses

Convention and Comparison of all three forms of Phosphorus follows

Phosphorus and Its Role

Phosphate and PMPD Comparison

- Phosphates are produced by neutralizing phosphoric acid with base such as KOH and ammonia. Whereas potash is given as salts of chloride, sulphate, nitrate and phosphate as fertilizers to crop plants through soil.

  PMPD is produced by splitting phosphorus and attaching K with catalytic technology.

- Phosphate is a source of nutrients and plays a vital role in plant metabolism but has limitations in applications to crop plants. Due to uncertainty in its uptake by crop plants, phosphate-based fertilizers are not supposed to have role in stress. However, potash has a key role in stress management in crop plants.

  Active P and K from PMPD alleviate all forms of stresses in crop plants.

- Due to the chemical composition of phosphatic fertilizers, they are poorly soluble in water e.g. mono potassium phosphate is 22% soluble i.e. 220 grams in one litre of water. DAP is approximately 20% water soluble.

  Technical molecule of PMPD is 180% water soluble i.e. 1800 grams in one liter.

- Phosphate fertilizers are not readily taken up by the foliage of many plants and require to be delivered through soil: 4% to 25% of applied P and K fertilizers get absorbed through roots depending on soil and environmental conditions.

  Majority of PMPD can easily be taken up by leaves, stems, and roots of crop plants.

- The mobility of phosphate fertilizers in the soil is limited leading to rapid localized depletion of phosphorus in the rhizosphere, resulting in phosphorus deficiency.

  PMPD does not get fixed in any kind of soil and is easily absorbed by roots.

- Potash fertilizers also have problems similar to phosphate fertilizers. In spite of potash being available in soil, potash deficiency is noticed in crops.

  Combination of phosphorus and potash in PMPD is particularly very synergetic.

Phosphorus and Its Role

Phosphate and PMPD Comparison

- Fixation calls for frequent re-applications of phosphate fertilizers, which leads to leaching of phosphate into groundwater resulting in eutrophication of lakes, ponds and streams. It creates health issues for living beings. PMPD, in comparison with conventional fertilizers, is required in very small quantities and it does not get fixed in any kind of soil. Hence PMPD is very safe in soil.

- Phosphate fertilizers inhibit the beneficial symbiosis between roots and mycorrhizal fungi.

  PMPD supports the beneficial symbiosis between the roots and mycorrhizal fungi and prevent the growth of pathogenic fungi and other soilborne pathogens by inhibiting oxidative phosphorylation in fungal pathogen.

- Traditional P and K fertilizers do not support the uptake of other micronutrients.

  PMPD supports the uptake of other micro nutrients by increasing root biomass.

- Soil loses its quality and fertility as well as increases salinity of groundwater with excess application of P and K fertilizers.

  PMPD does not pollute groundwater and helps to improve the quality of soil. PMPD facilits the ionization of soil minerals and these ions can be easily taken up by roots.

Soybean from PMPD-treated Plant Soybean from Control Plant

Phosphorus and Its Role

Phosphate and Phosphite Comparison

- PO_3^{-} first came into limelight when it was thought to overcome the shortage of PO_4^{-} during World War II.
- Since 1970, PO_3^{-} has been studied by many universities in USA, Europe, and elsewhere at molecular level for its role as fungicides, fertilizers and bio-stimulants.
- Potassium salt of phosphorous acid or potassium salt of phosphonic acid or potassium phosphite, is nothing but an ion compound of PO_3^{-}. These are different names of the same molecule.
- Mono potassium salt $K^{+}(H_2PO_3)^{-}$ or di potassium salt $K_2^{+}(HPO_3)^{-}$ of $PO_3^{-}$is called potassium phosphite. Aluminum salt of organic phosphorous acid is a phosphonate called as a fosetyl - Al or aluminum tris (O-ethyl phosphonate), these phosphonates can be used as fungicide or pesticide.
- PO_3^{-} has direct and indirect mode of action on phytopathogens. It is being reported that fungal diseases caused by Oomycete are controlled by the PO_3^{-} to the extent of 60 to 70% in combination with appropriate fungicide.
- PO_3^{-} does not take part directly in photosynthesis, root growth, respiration and also does not take part in any ATP and NADPH synthesis like PO_4^{-}. Although the mobility of PO_3^{-} and PO_4^{-} are similar, there is no evidence to suggest that plant can take PO_3^{-} as a source of PO_4^{-}.
- PO_3^{-} after entering into the plant remains stable throughout the life cycle and no known metabolism in the plant can convert the PO_3^{-} into PO_4^{-} and use it as a nutrient. Higher concentration of PO_3^{-} hinder the uptake of PO_4^{-} and is toxic to almost all species. Hence PO_3^{-} is applied to crop plants very cautiously.
- The recommendation of PO_3^{-} is 1 to 2 kg per acre (if in liquid form i.e. 1 lit. to 3 lit. per acre) in 2 to 5 treatments in the season. It is reported that majority of crop plants can die with excess use of PO_3^{-} ion.
- PO_3^{-} was found to have a negative effect on the growth of PO_4^{-} deficient plants by suppressing the typical molecular & developmental responses to PO_4^{-} deficiency.

Phosphorus and Its Role

Phosphate and Phosphite Comparison

- The effect of PO_3^- on crop plants is not consistent, but depends strongly on the PO_4^- status of plants. In most cases, the deleterious effect of PO_3^- is evident in PO_4^--starved plants but not in PO_4^--sufficient plants.
- PO_3^- ion and nutrient PO_4^- are strangers and incompatible with each other. The transport path of both the ions in the plant is same. Hence it is reported, that PO_4^- sufficient plant does not respond to PO_3^- in disease incidence. PO_3^- has adverse effect on growth when plants are PO_4^- deficient. PO_3^- enters into the plant quite faster than PO_4^- does and hinders further uptake of PO_4^- as both share the same transport channel.
- The various defence pathways including SAP (Shikimic acid pathway) are assumed to be triggered to a limited level inspite of effective application and further utilization of both PO_3^- and PO_4^-.
- Since the chemistry of PO_3^- and PO_4^- is mutually not supportive, that limits in the utilization of these ions even after proper applications of both.
- Al though some products claim to be a combination of PO_3^- and PO_4^- in their formulation, due to their antagonism, combination fails to provide the synergy.
- PO_3^- and PO_4^- taken together consistently show that plants are incapable of directly using PO_3^- as phosphorus source and thus PO_3^- cannot substitute PO_4^- fertilizer.
- It appears that during enzymatic biochemical reactions in living organisms, PO_4^- binding sites recognize three of the four O atoms, and the remaining O that protrudes from the surface of PO_4^- molecule to become available for taking part in enzymatic reactions. Hence, PO_3^- can not take part in similar biochemical reaction as because its hydrogen atom protrudes from the surface of the enzyme instead of the O atom in PO_4^-. Therefore, most of the enzymes involved in phosphoryl transfer reactions can readily differentiate between PO_4^- and PO_3^-.
- Role of PO_4^- in stress management is reported but warrants further confirmation.

For references and further studies refer 1 to 11 reports from the reference list

Phosphorus and Its Role

Phosphate and Phosphite Comparison

It is being reported that PO_3^- has direct and indirect modes of action against Oomycetous fungi. Po_3^- directly inhibits oxidative phosphorlylation, a process in fungal metabolism. The chemical alteration produces elicitors which are recognized by the receptors that trigger the plants defence response, is the indirect mode of PO_3^- action. For adequate results, PO_3^- is recommended in combination with fungicide. PO_3^- is not at all recommended and used for viral and bacterial infections and many other fungal diseases.

Active phosphorus from PMPD with a complex mode of action is believed to stimulate various metabolic processes in the plant to fight against invading fungal, viral and bacterial phytopathogens. Quick and effective recovery is noticed with standalone application of PMPD in post infection of various diseases. Triggering of elicitors response, synthesis of secondary metabolites, translocation of bio-energy, effective assimilation of nutrients, recovery from stress and bringing back the plant to normal conditions by increasing production of primary metabolites are the key functions played by PMPD.

PO_3^- is not recommended when crops are in the dormant stage or under stress. PO_3^- is believed to act as a preventive measure that is before any disease occurs. PMPD is particularly effective when crops are in dormant state or under stress. In such situations higher doses of PMPD (6 to 8 grams per litre of water) are applied through spray. If required, PMPD spray is repeated at 2 to 3 days intervals. PMPD has a definite role both as preventive as well as curative measures.

PO_3^- neither reduces fungicide application nor is recommended as a substitute for P and K fertilizers.

As observed in different trials, PMPD lowers the chemical load on different crops from 50% to 100% without deteriorating quality or lowering yields. Both yield and quality in PMPD-treated plants are higher in comparison with traditional methods.

Phosphorus and Its Role

PMPD and Phosphite Comparison

- PMPD does not have any phytotoxicity or no know side effects even if used in excess or sprayed more frequently. This is not the case with PO_3^-. A higher dose of PO_3^- is reported to be phytotoxic to most plant species, and 8 grams of PO_3^- per litre of water is fatal to all the plant species.

  PMPD (6 to 8 grams per litre of water) is sprayed on sugarcane for luxuriant growth and quality improvement. Grape and pomegranate growers apply 4 to 8 sprays of PMPD in the season by using 6 to 12 kg PMPD per acre to achieve several advantages which can lead towards sustainable and profitable cultivation.

- PO_3^- has very a limited role under specific conditions in particular species of plant. It is being reported that application of PO_3^- in productive stage shrinks and hinders further development in plants.

  PMPD can be applied to any crop at a given stage to get the produce of uniform size, color, as well as higher brix level along with better keeping quality. PMPD induces defence responses of plants and also maintains better growth, achieving higher yields and quality.

- Once in the plant PO_3^- remain stable throughout the plant life cycle.

  PMPD may breaks down inside the plant and supplies both PO_3^- and PO_4^- in adequate quantities.

- Active phosphorus from PMPD can overcome the limitations of nutrient based PO_4^- in agriculture, whereas PO_3^- limits the advantages of PO_4^-.

- PO_3^- and PO_4^- compete with each other.

  PMPD does not have any antagonistic effects on PO_4^-. Hence phosphorus from PMPD is unique and one of its kind in agriculture.

For references and further studies
refer 11 to 16 reports from the List of References

Comparison of PMPD with Potassium Phosphite

Potassium Phosphite (Phosphonate)

Spray Treatment : 8 gm / liter of water

Before spray

72 hours after spray
Phosphites are Phytotoxic

Potassium Phosphite (Phosphonate)

Spray Treatment : 8 gm / liter of water

Before spray

72 hours after spray
Phosphites are Phytotoxic

Comparison of PMPD with Potassium Phosphite

PMPD

Spray Treatment : 8 gm / liter of water

Before spray

72 hours after spray
PMPD is non-toxic

PMPD

Spray Treatment : 8 gm / liter of water

Before spray

72 hours after spray
PMPD is non-toxic

Introduction

When Efforts Spurred by Intuition
Molecule Evoked and Emerged as a PSAP

PSAP molecule is the experimental inclination of catalyst science.
Catalyst science is the science that starts where chemistry ends.

PMPD Technology

Proven on farmer's fields and tested by Agricultural Research Institutations

☛ Increases crop productivity ☛ Reduces cost of cultivation

Improves produce quality and retains nutritional values

- PMPD application is easy to handle and can be used without much change in existing agricultural practices.
- Application of PMPD complements existing agricultural production technology as well as emerging technologies such as precision agriculture.
- PMPD has been tried and tested on farmers' fields. PMPD technology has proven that it significantly increases crop yield and improves produce quality. PMPD also induces tolerance to diseases, pest, and various types of stress in crop plants. PMPD can be applied to a wide range of crops and can be instrumental in bringing in the most needed agricultural revolution.
- PMPD is very effective in almost all crops: it improves plant health, induces stress tolerance, reduces chemical load, increases yield (15%-50%) and improves quality of produce (sweetness, colour, size, aroma, luster and keeping quality) ultimately benefitting farmers and consumers in terms of food safety.

Introduction

- PMPD is an innovative molecule invented and launched in the year 2010 by Indian scientists in agriculture for the first time in the world.
- Active phosphorus from PMPD is the highly soluble form of Phosphorus which along with Potash alleviates abiotic and biotic stress in plants.
- After working relentlessly for 6 years on the split technique, we developed the highly active Phosphorus and used it in PMPD.
- In PMPD, Potassium is given along with Phosphorus to support as well as rebuild various metabolic processes in crop plants.
- Isha Agro from India has such a unique type of formulation in their portfolio.
- In India, farmers from many states are applying PMPD on thousands of hectares, growing healthier crops and harvesting bumper yields with superior quality of produce.
- PMPD can be used successfully on all kinds of crops like vegetables, fruits, cereals, flowers, herbs and spices as a supplementary fertilizer and has proved a very effective nontoxic formulation that triggers plant defences at higher level for longer period of time.

  PMPD-treated plants react and respond very effectively against various diseases including the following,

  (1) Downy mildews

  (2) Damping off and seedling rots caused by *Pythium* sp, *Rhizoctonia* sp, *Fusarium* sp, etc.

  (3) Phytophthora diseases such as late blight, collar rots, root rots, leather rots, red stele etc.

  (4) White rust

  (5) Scabs and diseases caused by *Cercospora* and *Phomopsis.*

  (6) Bacterial blight caused by *Xanthomonas campestris*, *xanthomonas auxonotolis, xanthomonas malvacearum.*

  (7) Mosaic caused by viral infection.

Innovation

PSAP - ProPhite are Trade Mark of PMPD

PSAP - ProPhite

Feed the Crops and Not the Soil

Indian Innovation

International Acclaims

Indigenous Manufacturing

'P' and 'K' Formulation approved for Organic Farming

Exceedingly water soluble nutrients apply through the sprays

PMPD is 180% water soluble i.e. 1800 gm soluble in 1 Liter of water

It is a plant and human friendly combination applicable to C_3 & C_4 plants

PMPD contain Phosphorus as P_2O_5(WS) 40% and Potash as K_2O (WS) as 40%

Innovation

PMPD - Potassium Meta Phosphate Dimer

CSIR - NCL Pune Reported PMPD Structure

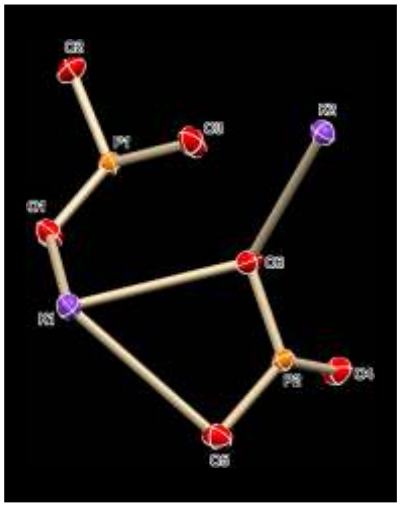


Figure (a)

ORTER view of compound for PMPD in the asymmetric unit showing the atom numbering scheme. Diplacement ellipsoids are drawn at the 70% probability level.

Phosphorus with 3 and 5 - Valences

(Applied For Patent)

Research started in year 2002-03 to discover phosphorus complex. By using catalysts O & H bonds of phosphorous, were destabilized. With the split technique potash was attached to this phosphorus *in-setu*. Molecule was stabilized with 3rd catalyst and PMPD discovered in 2010.

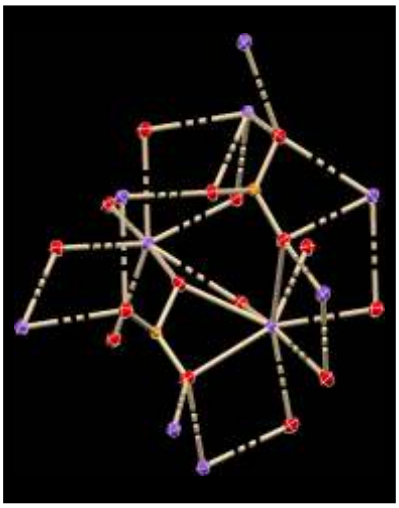


Figure (b)

The complete structure of the PMPD complex.

PMPD reduces pesticide and fertilizer use

PMPD improves plant physiology even in marginal conditions

PMPD plays role in synthesis of primary and secondary metabolites

PMPD - ProPhite For C_3 Crop Plants

Crop wise Spray Advise

Spray Dose: Mix 6 gm ProPhite per Liter of water

Method

1) Do not mix any chemical while making solution
2) Spray the leafs thoroughly inside-out by solution
3) Soil : 2 Kg / Acre through drip 2 time in 15 days

(Spray 150 to 250 Liters Solution / Acer / Spray base on canopy)

Crops	Spray Starts	Qty** / Spray / Acer	Total Sprays	Spray Interval	Qty /Acer / Season
Ginger, Turmeric	30 DAP*	1.0 to 1.6 Kg	5 to 8	20 to 25 Days	6 to 10 Kg
Strawberry	Before Flowering	1.0 to 1.6 Kg	5 to 6	10 to 15 Days	6 to 8 Kg
Onion, Potato	30 DAP*	1 Kg	3 to 4	8 to 10 Days	4 to 5 Kg
Tomato, Chilly	30 DAP	1.0 to 1.6 Kg	10 to 12	10 to 15 Days	10 to 12 Kg
Fruit Crops	Before Flowering	1.6 to 2 Kg	6 to 8	8 to 10 Days	12 to 18 Kg
Cotton	30 DAP	1.4 to 2 Kg	3 to 4	10 to 15 Days	5 to 6 Kg
Flowers	Before Flowering	1.2 Kg	5 to 6	10 to 12 Days	6 to 8 Kg
Herbs, Spices, Tea	Before Flowering	1.0 to 1.6 Kg	6 to 8	15 to 20 Days	8 to 10 Kg

*DAP – Days after plantation ** Qty – Quantity

ProPhite
(00 : 40 : 40)

1 Kg Packing

ProPhite is applied in export cultivation practices
One Lacs + growers are using it regularly in grapes

Spray Advise in Grapes

Dose: 4 gm ProPhite per Liter of Water. Apply in High Volume Spray

Spray schedule in foundation pruning : Apply 4 Kg ProPhite per Acre in 3 Sprays
Spray ProPhite from 4 leaf stage in 15 days interval

Spray schedule in fruit pruning : Apply 15 Kg ProPhite per Acre in Ten Sprays

Weather favors disease development then apply two sprays additionally
ProPhite + Fungicide in 2 to 3 days interval.

Spray Schedule

Stage	After Pruning	Spray	Spray Volume	Spray with*
Ponga Stage	10 to 12 days	One	200 to 250 L/A	fungicide
Crust Colour	20 to 25 days	One	200 to 250 L/A	fungicide
Pre Flowering Stage	30 to 35 days	One	250 to 300 L/A	Plain spray
Flowering Stage	35 to 40 days	Two	300 to 400 L/A	Plain spray
2 nd Dipping	45 to 50 days	One	300 to 400 L/A	GA
2 to 3 mm size stage	50 to 55 days	One	300 to 400 L/A	Plain spray
4 to 5 mm size stage	60 to 65 days	One	300 to 400 L/A	Plain spray
Berry Development	70 to 75 days	One	300 to 400 L/A	Plain spray
Berry Development	75 to 80 days	One	300 to 400 L/A	Biologicals

*Check the compatibility of mixture first use on small area and then spray

PMPD - PSAP For C_4 Crop Plants

PSAP

(00 : 40 : 40)

1 Kg Packing

PSAP Spray Advise in Sugarcane

Apply 12.5 to 15 Kg PSAP per Ha in 3 sprays

Spray starts in sugarcane at 6 to 7 leafs stage.

Spray sugarcane leafs inside out with 30 days interval

PSAP Spray Schedule

Stage	Spray Volume	Quantity / Spray
50 to 60 Days	400 Liters / Ha	4.0 Kg / Ha
80 to 90 Days	600 Liters / Ha	5.0 Kg / Ha
110 to 120 Days	800 Liters / Ha	6.0 Kg / Ha

Benefits of PMPD

Increases crop yield by 15 - 50%, Reduces Plant Protection Chemicals and Fertilizer use by 50%, Improves produce quality benefitting in export

Tested by Premier Sugarcane and Sugar Institutes: NSI; International Academy; ICAR-IISR; SAU's; ICAR-NRCG and Reported PSAP (PMPD) bio-efficacy in C_3 and C_4 plants.

Gist of Reports

Increases sugarcane yield by 25 Tons/ha
Improves sugar recovery by 0.5 % in CCS

Summary:

1) **Central Sugarcane Research Station, Padegaon, MPKV- Rahuri, Dist. Nagar, Maharashtra.**

Reported the impact of PSAP on yield and quality of cane in a tropical region. The results showed that there is an increase in care yield to the tune of 20.80 MT/ha and 0.26% improvement sugar recovery. Studies also revealed that even after 50% reduction in RDF, (Recommended Dose of Fertilizer) split spray of PSAP/ha increased cane yield by 20.9 tons/ha and recovery improved by 0.26% in CCS.

2) **UPCSR- Uttar Pradesh Council of Sugarcane Research, Shahjanpur**

Tested the impact of PSAP for two years at two locations in SRI - Central & GSSBRI - Seoria Eastern Uttar Pradesh, i.e., in a sub-tropical region. It revealed impressive impact of PSAP on yield and quality under different geo graphical conditions. Cane yield increased by 21.4 to 24.4 MT /ha and recovery improved in CCS by 0.36% to 0.5% unit respectively in Central & Eastern Uttar Pradesh.

3) **NSI – National Sugar Institute, Kanpur, U. P., India**

Collaborative Research Project was conducted for testing of PSAP - bio-efficacy on cane in two plantations & one ratoon crop. It is concluded that application of PSAP through foliar sprays (four sprays at 60, 75, 90 & 120 DAP) gave significantly better results than control w/o PSAP. With 100% RDF of NPK (180:80:80) + PSAP in sugarcane increased yield by 39% & 46% in plant & ratoon respectively; 1.85% to 2.03% improved recovery in CCS unit.

4) **CSAUT - Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, U. P., India**

Testing of PSAP, “Potassium salt of active phosphorus” a research molecule was conducted on sugarcane during the years : 2019 - 20 and 2020 – 2021 for two seasons. It was reported that application of PSAP@ 12.5 Kg/ha with RDF. Increased yield by 23.4 tons /ha and 36.3 tons / ha with 1.03 % to 0.45 % recovery improvement in CCS unit.

Tested by Premier Sugarcane and Sugar Institutes

Split application of PSAP resulted in an average increase in sugarcane yield by 31.54% and improved recovery by 0.75% in CCS unit

Institute	CSRS	SRI	GSSBRI	NSI	NSI	CSAUT	CSAUT
Year	2014-15	2016-18	2016-18	2019-21	2020-21	2019-20	2020-21
Sugarcane	Plantation	Plantation	Plantation	Plantation	Ratoon	Plantation	Plantation
Variety	CoM 0265	UP 05125	UP 05125	Co 0238	Co 0238	Co 0238	Co 0238
PSAP Dose	7.0 Kg / Ha	12.5 Kg / Ha	15 Kg / Ha	12.5 Kg / Ha	12.5 Kg / Ha	12.5 Kg / Ha	12.5 Kg / Ha
Control Plot -Yield **Recovery in CCS%**	1636 Q / Ha **13.54**	787 Q / Ha **12.35**	679 Q / Ha **12.31**	720 Q / Ha **12.41**	681.5 Q / Ha **11.97**	686 Q / Ha **9.02**	707.6 Q / Ha **13.53**
Treated Plot - Yield **Recovery in CCS%**	1844 Q / Ha **13.80**	1001 Q / Ha **12.67**	923 Q / Ha **12.81**	1001 Q / Ha **14.26**	998 Q / Ha **14.01**	920 Q / Ha **10.05**	1076 Q / Ha **13.98**
Yield Difference - YD	208 Q / Ha	214 Q / Ha	244 Q / Ha	281.7 Q / Ha	316.7 Q / Ha	234 Q / Ha	363.5 Q / Ha
Recovery Improved	**0.26 CCS %**	**0.32 CCS %**	**0.50 CCS %**	**1.85 CCS %**	**2.03 CCS %**	**1.03 CCS %**	**0.45 CCS %**
Ethanol @ Recovery... A	3.89 Lit / Ha	4.93 Lit / Ha	8.79 Lit / Ha	37.42 Lit / Ha	46.18 Lit / Ha	17.35 Lit / Ha	11.76 Lit / Ha
Ethanol (7.2 X YD) + A	1502 Lit / Ha	1546 Lit / Ha	1766 Lit / Ha	2060 Lit / Ha	2321 Lit / Ha	1702 Lit / Ha	2626 Lit / Ha
Extra Income to Farmers @ Rs. 325 / Q	Rs. 67,600/Ha	Rs. 69,550/Ha	Rs. 79,300/ Ha	Rs. 91,552/Ha	Rs. 102,927/Ha	Rs.76,050/Ha	Rs.103,350/Ha
NP to Mil from Extra Ethanol @ 63.45/Lit 7/Lit distillation Cost	Rs. 17,188 /Ha	Rs. 17,772 /Ha	Rs. 20, 391 /Ha	Rs. 24, 735/Ha	Rs. 28, 093 /Ha	Rs.20, 028/H	Rs. 44, 888 /Ha

PSAP - Cost to Benefit Analysis (In INR)

Production	Extra / ha	Rate in Rs.	Extra Income
Sugarcane	25 tons	3500 / tons	Rs. 87,500 / ha
Sugar	0.36 tons	33 / Kg	Rs. 11,880 / ha
Bio-Ethanol (CJ @ 72 Lit/MT)	1800 Lit	63.45 / Lit	Rs. 11,4210 / ha
Extra Income Potential Created by PSAP .... Rs. 2,13,590 / ha			
PSAP require 15 Kg / ha @ Rs. 1450 Rs. 21,750 / ha			
Income Potential Created By PSAP ..... Rs. 2,13,590 / ha			
Return to Farmer on PSAP Investment 400%			

Profits are Estimated Base on Prevailing Prices

PSAP Increases Yield By 25 tons/ha
Improves Recover By 0.5% in CCS Unit

Resulted in 30% Increment in Receipts & 100% Improvement in Profits

Benefits (Highlighted in Red)

Particulars	C-Molasses	Partial Syrup + CM	BHM	Partial Syrup +BH
Sugar Plant (TCD)	6000	6000	6000	6000
Sugar Mill Working (DPA)	125 → 162	125 → 162	125 → 162	125 → 162
Sugar Production Lac Tons	0.844 → 1.128	0.741 → 0.778	0.712 → 0.972	0.678 → 0.715
Rs.32.75/Kg and Recover @	11.25% → 11.75%	9.88% → 10.38%	9.50% → 10.0%	9.04% → 9.54%
Total RS Production LL / A	103 → 133	154 → 200	162 → 210	238 → 308
In 55KLPD @ Total Crushing	@ 13.75 %	@ 20.62 %	@ 21.6 %	@ 31.7 %
Total Ethanol Production LL/A	98 → 127	147 → 191	154 → 199	226 → 293
@ 60KLPD, Ethanol Increase	0.0 % → 30.0 %	50.3 % → 94.7 %	57.1 % → 103.6 %	130 % → 199 %
Working Days / Annum	188 → 243	270 → 347	270 → 350	270 → 350
Total Receipts (Rs. Cr.)	316 → 410	322 → 418	327 → 425	321 → 417
Direct Benefits from saving in	Nil → 11	Nil → 12	Nil → 16	Nil → 11
Cost of Sugar Production (Cr)	@ Rs. 1.0 / kg	@ Rs. 1.5 / kg	@ Rs. 1.6 / kg	@ Rs. 1.6 / kg
Indirect Benefits (Rs. Cr.)	Nil	2.59 → 3.36	3.50 → 4.55	2.14 → 2.78
Receipts + Benefits (Rs. Cr.)	316 → 421	324 → 434	330 → 445	323 → 431
Total Expenses (Rs. Cr.)	304 → 395	305 → 396	305 → 396	307 → 399
Net Profit (Rs. Cr.)	12 → 26	19 → 38	25 → 49	16 → 32
Additional Net Profit (Rs/MT)	108	253	171	214

(Ethanol Price in INR : CM - 45.69, BH - 54.27, CJ - 63.45)

ICAR - National Research Center for Grapes, Pune, India

Report of PSAP - ProPhite against Downy Mildew disease of grapes and Yield improvement

Summary:

Tested PSAP - ProPhite in comparison with potassium phosphite for the control of various diseases in grapes during the year 2016-17 and 2017-18. PSAP - ProPhite proved far superior in controlling various diseases like *downy mildew* and *anthracnose* in grape. It was also observed that split sprays of PSAP - ProPhite can reduce fungicide sprays by 50 %. PSAP - ProPhite also improved the yield by 34.80% to 68.66% when applied singly or in combination with fungicides, respectively.

- The Bioefficacy and phytotoxicity of PSAP - ProPhite & the standard check fungicide (cymoxanil + mancozeb) was tested.
- Six sprays of ProPhite (4g / l) and check fungicide (cymoxanil 8% + mancozeb 64%) were given at an interval of 10 days after pruning under the favorable conditions for development of disease.
- The treatment PSAP - ProPhite followed by curzate (4 applications) followed by successive application of ProPhite was found to be most effective in downy mildew control (43.38% of disease control) followed by ProPhite + 2 applications of curzate + ProPhite (38.98%). The treatments also recorded yield of 14.92kg / vine & 13.13 kg /vine respectively as against 9.09 kg per vine in the control.
- Treatment with only ProPhite resulted in 38.20% disease control as against 38.98% when PSAP - ProPhite was used in combination with recommended fungicide, which is at par.

Bioefficacy of PSAP - ProPhite in management of Downy Mildew disease

Sr No.	Treatments	PDI of downy mildew (%) on leaves	Disease Control %	Yield Per Vine (kg)	% increase in Yield over control
1	Control	13.06	——	9.09	——
2	ProPhite @ 4 g / L	13.93	38.20	12.83	41.14
3	Cymoxanil 8 % + mancozeb 64% (Curzate)	15.56	31.38	11.68	28.49
4	ProPhite + curzate (2 sprays) followed by PhoPhite	12.50	38.98	13.13	44.44
5	ProPhite + curzate (4 sprays) followed by PhoPhite	10.87	43.38	14.92	64.13
	CD (P=0.05)	2.37	——	3.96	

ICAR - Nitional Research Center for Grapes, Pune, India

Report of PSAP - ProPhite against Anthracnose disease on grape leaves and Phytotoxicity

Summary:

- ProPhite (4 g / l) and Thiophenate methyl 70% WP(0.71 g / l) sprays were given when the conditions were favorable for development of disease
- Four sprays were given for disease management after pruning.
- ProPhite @ 4 g/l followed by thiophenate methyl (3 applications) & ProPhite @ 4 g/l followed by thiophenate methyl (2 applications) followed by successive application of ProPhite recorded significantly lower PDI of anthracnose
- Integration of spray application of ProPhite with thiophenate methyl resulted in lowering number of sprays of chemical fungicide.
- No phytotoxicity symptoms were developed on leaves even after application of 8 g/ l of PSAP - ProPhite.

Sr No.	Treatments	PDI of anthracnose (%) on leaves	Disease Control %
1	Control	20.50	——
2	ProPhite @ 4 g / L	19.37	38.04
3	Thiophenate methyl 70% WP	16.75	41.23
4	ProPhite + Thiophenate (3 applications) followed by ProPhite	15.12	46.95
5	ProPhite + Thiophenate (2 applications) followed by ProPhite	16.18	43.23
	CD (P=0.05)	2.71	2.74

ICAR - Nitional Research Center for Grapes, Pune, India

PSAP - ProPhite (PMPD) on Grape berries
Evaluation of Residue and Persistence Study

- Three sprays of ProPhite as foliar spray @ of 4g/l (T1) and 8 g/l (T2) were applied at 7 days interval along with untreated control plot (T0).
- Samples of grape berries were collected within 2 hours at different time period I e 1, 3, 5, 7, 10, 15, 21, 30, 45, 60 days.
- Residue analysis of ProPhite as phosphonic acid was carried out using LC-MS/MS.
- The dissipation behaviour of ProPhite showed rapid decline during the initial phase which slowed down with the passage of time. The ProPhite residue dissipated with a half life of 10.5 & 14.5 days for T1 & T2 respectively
- Application of ProPhite @ 4g/l is effective in disease control and the residue of ProPhite as phosphonic acid at harvest was less than 1 mg / kg

Table 3 Residue study of ProPhite in grape berries as phosphonic acid residues

Phosphonic acid residues (mg/kg) Grapes Berries			
Sampling (Days)	**T0**	**T1**	**T2**
0	<LOQ	14.50	28.93
1	<LOQ	12.33	23.50
3	<LOQ	9.85	22.20
5	<LOQ	8.89	21.06
7	<LOQ	8.36	20.10
10	<LOQ	8.07	16.03
15	<LOQ	6.70	14.43
21	<LOQ	4.73	10.36
30	<LOQ	1.58	4.04
45	<LOQ	1.01	2.82
60	<LOQ	0.81	2.25
Half-life (days)	<LOQ	10.5	14.5

JNKVV, College of Agriculture, Ganj Basoda, Madhya Pradesh, India

Report of PSAP in Soybean
To control Insect, pest & predator population and yield improvement

Summary:

Research trials for evaluation of PSAP for insect and predator on standing crop and bio efficacy on soybean conducted during *Kharif*, 2018 – 19. Higher yield was recorded (14.07%) in soybean by use of PSAP. It was also found superior for control of insects population. Effect of PSAP on the natural enemies population; data pertaining to the effect of different treatments on population of natural enemies did not show any effect on population of natural enemies i.e. Lady Bird Beetle in soybean ecosystem. The results were statistically on par in all treatments. No phyto-toxicity effect of PSAP on soybean crop was observed in any treatment during the experiment.

RDF 50% P&K + 50% RPM with foliar spray of PSAP @ 4g/l was effective in improving yield and reducing chemical use

Foliar spray of PSAP @ 4g/l was effective in controlling the major pests of soybean i.e. *Green semiloopar, Chrysodeixis acuta, Spodopetera litura* and *White fly* and yield was at par with T1.

Foliar Sprays at-

1. Pre Flowering
2. 55 DAS
3. 70 DAS

Dose : 2.5Kg PSAP /ha/sray

Treatments	Yield	No. of Larvae Per meter row length (Green Semiloopar & Chrysodeixis acuta)	No. of Larvae Per meter row length (Spodopetera Litura)	Population of White Fly Per 3 Leaves	Number Of Coccinellid grubs per plant	% Increase Over Control (T_1)
T_1 : RDF + RPM	17.05	10.46	11.14	12.55	1.25	0.00
T_2 : T_1 + PSAP@4g/l	19.45	6.44	7.51	8.34	1.33	14.07
T_3 : RDF + 50% RPM	15.55	11.85	12.38	14.36	1.44	(8.79)
T_4 : T_3 + PSAP@4g/l	18.65	7.38	8.49	9.63	1.45	9.38
T_5 : RD of N + 50% P&K + RPM	15.38	13.17	13.32	14.99	1.36	(9.79)
T_6 : T_5 + PSAP@4g/l	18.12	7.92	8.88	10.67	1.25	6.23
T_7 : RD of N + 50% P&K + 50% RPM + PSAP 4g /l	17.27	8.98	9.87	11.59	1.45	1.29
CD (P=0.05)	5.11	0.52	0.56	0.52	NS	

PSAP @ 8 & 12 g /l did not show any Phytotoxicity symptoms

ICAR - IISR Indore On AICRP in Soybean, M. P., India

Report of PSAP in Soybean
To improve yield and reduce use of RDF and RPM by 50%

Summary:

Agronomical trial on, "Bio-efficacy evaluation of potassium salt of active phosphorus (PSAP) on soybean" was conducted at ten location/centers of AICRP Soybean during *kharif*, 2020 -21.

PSAP @ 6 g/l resulted in an average increase in soybean yield of 10.78% across different locations and agro climatic zones.

PSAP @ 9 g/l resulted in an average increase in soybean yield of 27.90% and reduced recommended P & K and RPM by 50% across different locations and agro climatic zones

Foliar Spray of PSAP at critical growth stages of soybean @ 6 g/l & 9 g/l Caused significant increased in grain yield and the yield contributing parameters

In southern zone the improvement in the yield over control ranged from 10.63% when PSAP was applied @ of 6 g/l and 53.13 % when applied @ 9 g/l.

In Northern plain the improvement in the yield over control ranged from 2.28 % when PSAP was applied @ of 6 g/l and 9.05 % when applied @ 9 g/l.

In Eastern plain the improvement in the yield over control ranged from 4.10% when PSAP was applied @ of 6 g/l and 10.7% when applied @ 9 g/l.

In North East hilly region the improvement in the yield over control ranged from 22.04% when PSAP was applied @ of 6 g/l and 27.99% when applied @ 9 g/l.

Effect of PSAP on Soybean Yield in Central Zone

1. Sehore (Madhya Pradesh)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K 50% RPM
No PSAP	17.49	16.46	15.64	15.43
PSAP @ 6 g/l	17.7 (1.2)	16.67 (1.27)	15.84 (1.27)	15.84 (2.65)
PSAP @ 9 g/l	17.9 (2.3)	16.67 (1.27)	16.67 (3.81)	16.05 (4.01)
CD (0.05)	1.88			

2. Amravati (Vidarbha, Maharashtra)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K 50% RPM
No PSAP	20.65	16.22	14.24	13.78
PSAP @ 6 g/l	21.85 (5.81)	17.45 (7.58)	15.25 (7.09)	14.86 (7.83)
PSAP @ 9 g/l	22.76 (10.21)	16.67 (13.99)	15.14 (6.32)	16.05 (9.86)
CD (0.05)	2.93			

3. Kota (Rajasthan)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K 50% RPM
No PSAP	12.17	12.07	9.83	9.50
PSAP @ 6 g/l	12.67 (4.1)	12.47 (3.31)	10.67 (8.45)	10.33 (8.7)
PSAP @ 9 g/l	12.75 (4.76)	13.00 (7.7)	11.00 (11.90)	10.50 (10.52)
CD (0.05)	1.88			

Results

- In Central zone, foliar application of PSAP @ 6 g/l and 9 g/l increases 4.94 and 7.22 % soybean yield, respectively in different nutrient and plant protection management practices.

- 100 % RDF + RPM is at par with –
  - ✓ PSAP @ 9 g/l + 50 % P &K + 50 % RPM at Sahore
  - ✓ PSAP @ 6 g/l + 75 % P &K + 75 % RPM at Amravati
  - ✓ PSAP @ 6 g/l + 50 % RPM at Kota

ICAR - IISR Indore On AICRP in Soybean, M. P., India

Summary:

Effect of PSAP on Soybean Yield in South Zone

4. Adilabad (Telangana)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K + 50% RPM
No PSAP	19.5	17.65	14.67	11.11
PSAP @ 6 g/l	23.19 (18.92)	19.64 (11.27)	17.39 (18.54)	15.17 (36.54)
PSAP @ 9 g/l	29.86 (53.12)	22.36 (22.36)	19.68 (34.15)	16.32 (46.89)
CD (0.05)	3.26			

5. Dharwad (Karnataka)

Treat	100% P&K + RPM	75% P&K + 75% RPM	50% P&K + 50% RPM	No P&K + 50% RPM
No PSAP	25.00	24.00	22.67	18.00
PSAP @ 6 g/l	28.33 (13.00)	26.00 (8.33)	23.00 (1.45)	22.33 (24.05)
PSAP @ 9 g/l	31.92 (27.68)	27.67 (15.29)	24.67 (8.82)	22.63 (25.72)
CD (0.05)	3.69			

6. Pune (Maharashtra)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K + 50% RPM
No PSAP	24.95	24.41	23.05	22.7
PSAP @ 6 g/l	25.31 (1.44)	24.24	23.85 (3.47)	22.75 (0.22)
PSAP @ 9 g/l	26.19 (4.76)	24.76 (1.43)	22.7	22.88 (0.8)
CD (0.05)	1.36			

Results

- In Central zone, foliar application of PSAP @ 6 g/l and 9 g/l increases 12.47 and 22.31% soybean yield, respectively in different nutrient and plant protection management practices.
- 100 % RDF + RPM is at par with –
  - ✓ PSPA @ 9 g/l + without P & K + 50 % RPM at Adilabad
  - ✓ PSPA @ 6 g/l + without P & K + 50 % RPM at Dharwad
  - ✓ PSPA @ 6 g/l + 50 % P & K + 50 % RPM at Pune

Effect of PSAP on Soybean in Northern Plain, Eastern Plain and North East Hill Zone

7. Pantnagar (Uttarakhand)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K + 50% RPM
No PSAP	19.66	17.82	17.45	11.76
PSAP @ 6 g/l	20.11 (2.28)	17.4	18.19 (4.24)	12.5 (6.29)
PSAP @ 9 g/l	21.44 (9.05)	18.25 (0.03)	16.21	12.61 (7.22)
CD (0.05)	1.6			

8. Ranchi (Jharkhand)

Treat	100% P&K + RPM	75% P&K + 75% RPM	50% P&K + 50% RPM	No P&K + 50% RPM
No PSAP	18.57	17.89	14.97	11.95
PSAP @ 6 g/l	1933 (4.09)	19.04 (6.42)	15.63 (4.4)	12.16 (1.75)
PSAP @ 9 g/l	20.44 (10.07)	19.89 (11.18)	16.93 (13.09)	12.58 (5.27)
CD (0.05)	1.82			

9. Imphal (Manipur)

Treat	100% P&K + RPM	75% P&K +75% RPM	50% P&K +50% RPM	No P&K + 50% RPM
No PSAP	13.11	10.86	10.03	9.08
PSAP @ 6 g/l	16.00 (22.04)	12.89 (18.69)	11.47 (14.35)	10.67 (17.51)
PSAP @ 9 g/l	26.19 (27.99)	13.94 (28.36)	12.92 (28.81)	11.06 (21.80)
CD (0.05)	1.36			

Results

In Northen plain zone , foliar application of PSPA @ 6 g/l with 50% P&K & 50%RPM recorded at par yield with control.

In Eastern plain zone , foliar application of PSPA @ 9 g/lwith 50% P&K & 50%RPM recorded at par yield with control.

In North East Hill zone , foliar application of PSPA @ 6 g/l with 50% P&K & 50%RPM recorded at par yield with control.

RVSKVV, Gwalior, College of Horticulture, Mandsaur

Report of PSAP in Opium Poppy (*Papaver somniferum*) On yield improvement and disease control

Summary:

The field trials were conducted to evaluate the PSAP against Downy mildew and Powdery mildew. PSAP tested at AICRP M & AP research field, Mandsaur, for evaluation of bioefficacy of PSAP on Opium Poppy (Papaver somniferum). The Field trials have been conducted during 2019-2020, 2020–2021 and 2021-2022 for three seasons. From above experiment it is evident that 50% reduction of recommended pesticide spray for the crop + with PSAP @ 6 gm / liter shows maximum reduction in disease incidences and maximum increase in seed yield, latex and husk yield without any symptom of phytotoxicity.

Table 1 : Year 2021-2022

Sr. No.	Latex Yield (Kg)	Seed Yield (Kg)	Husk Yield (Kg)	Morphine	Downy Mildew PDI (%)	Powdery Mildew (%)
	Ha	Ha	Ha	%	Decrease in PDI(%)	Decrease in PDI(%)
T1 RDF + RPM	41.25	617.50	628.75	11.56	35.90	41.98
T 22 RDF + 50% RPM + PSAP @ 6g/l	55.00	690.00	717.50	12.77	47.86	53.09
% Increase Over Control (T1)	33.33	11.74	14.11	10.46	——	——

Table 2 : Year 2020-2021

Sr. No.	Latex Yield (Kg)	Seed Yield (Kg)	Husk Yield (Kg)	Morphine	Downy Mildew PDI (%)	Powdery Mildew (%)
	Ha	Ha	Ha	%	Decrease in PDI(%)	Decrease in PDI(%)
T1 RDF + RPM	39.13	621.38	631.25	11.75	30.63	40.66
T 22 RDF + 50% RPM + PSAP @ 6g/l	53.18	688.54	725.00	12.75	43.24	51.65
% Increase Over Control (T1)	35.90	10.87	14.85	8.51	——	——

RVSKVV, Gwalior, College of Horticulture, Mandsaur

Report of PSAP in Opium Poppy (*Papaver somniferum*)
On yield improvement and disease control

Summary:

Table 3 : Year 2019-2020

Sr. No.	Latex Yield (Kg)	Seed Yield (Kg)	Husk Yield (Kg)	Morphine	Downy Mildew PDI (%)	Powdery Mildew (%)
	Ha	Ha	Ha	%	Decrease in PDI(%)	Decrease in PDI(%)
T1 RDF + RPM	42.65	625.48	650.47	11.9	46.28	48.72
T 22 RDF + 50% RPM + PSAP @ 6g/l	53.85	818.85	835.87	12.8	52.47	55.45
% Increase Over Control (T1)	26.26	30.91	28.50	7.56	—	—

The foliar spray of PSAP @ 6g / l with 50% reduction in the recommended spray schedule was found to be effective in controlling major foliar diseases i.e. Powdery mildew and Downy mildew and improving seed, husk and latex yield

The Phytochemical morphine content was also increased significantly.

PSAP @ 6 g/l resulted an average increase in over all yield of 68.37% with 50% reduction of RPM

Latex 31.38%	Seed 17.84%
Husk 19.15%	Morphine 8.84%

MACS - Agharkar Research Institute, Pune, India

Absorption efficiency and physiological nutrient use efficacy of Phosphorus and Potassium applied through PSAP [PMPD] (00:40:40) & (00:52:34) in chickpea crop

Physiological Nutrient Use Efficiency:

Ability of a plant to transform nutrients acquired from fertilizer into economic yield (grain).

PE = (Y– Yo) / (U– Uo)

Where,

Y – Crop yield with applied nutrients (kg/ha)

Yo – Crop yield (kg/ha) in a control treatment

U – Total plant nutrient uptake (kg/ha) in a plot that received fertilizer

Uo – Total nutrient uptake (kg/ha) in control

Two fertilizers combination with two levels were used for comparisons along with control PSAP @ 4 & 6 g/l and 0:52:34 @ 4 & 6 g/l

A field experiment was laid out in a Randomized Block Design (RBD) with five treatments and three replications. The soil was medium black with the initial soil nutrition status as under

pH	EC (ds/m)	OC %	N Kg/ha	P Kg/ha	K Kg/ha
7.53	0.35	0.74	199.36	47.71	448

Two fertlizers viz. PSAP also called as potassium meta phosphate dimer (00:40:40) and other P K combination fertilizers (00:52:34) where used for foliar application at 30, 45 & 60 days of crop growth. The variety of chickpea “vikram” was used for the experiment.

The two fertilizers were applied as foliar sprays @ 4g/l and 6g/l. The observations on yield and yield contributing characters, the uptake of P & k due to foliar application and the physiological nutrient use efficiency was investigated.

MACS - Agharkar Research Institute, Pune, India

Absorption efficiency and physiological nutrient use efficacy of Phosphorus and Potassium applied through PSAP [PMPD] (00:40:40) & (00:52:34) in chickpea crop

Table 1: Quantity of nutrients applied through foliar spray

Treatment	Dose (g/lit)	Dose (kg/ha)	Quantity of Nutrient (kg/ha)	
			P_2O_5	K_2O
PSAP 0:40:40	4	2.00	0.8	0.8
PSAP 0:40:40	6	3.00	1.2	1.2
0:52:34	4	2.00	1.04	0.68
0:52:34	6	3.00	1.56	1.02
Water spray	—	—	—	—

Table 2: Quantity of phosphorus removed(kg/ha) from the soil

Tr No	Treatment	Initial soil available P (kg/ha)	After harvest soil available P (kg/ha)	P Removal from Soil (kg/ha)
1	RDF + PSAP 4 g /lit. water	47.71	46.5	1.21
2	RDF + PSAP 6 g /lit. water	47.71	44.52	3.19
3	RDF + 0:52:34 4 g/lit water	47.71	40.65	7.06
4	RDF + 0:52:34 6 g/lit water	47.71	45.5	2.21
5	RDF + Water spray (Control)	47.71	39.5	8.21

Table 3: Quantity of potassium removed (kg/ha)from soil

Tr No	Treatment	Initial soil available K (kg/ha)	After harvest soil available K (kg/ha)	K Removal from Soil (kg/ha)
1	RDF + PSAP 4 g /lit. water	448	415	33
2	RDF + PSAP 6 g /lit. water	448	421	27
3	RDF + 0:52:34 4 g/lit water	448	417	31
4	RDF + 0:52:34 6 g/lit water	448	408	40
5	RDF + Water spray (Control)	448	410	38

MACS - Agharkar Research Institute, Pune, India

Absorption efficiency and physiological nutrient use efficacy of Phosphorus and Potassium applied through PSAP [PMPD] (00:40:40) & (00:52:34) in chickpea crop

Table 4: Phosphorus uptake (kg/ha) due to foliar sprays of fertilizers in chickpea

Tr No	Treatment	Total uptake (kg/ha)	Contribution of Soil (kg/ha)	P Uptake due to fertilizers (kg/ha)	P uptake from soil applied fertilizer (kg/ha)	P uptake due to foliar spray of fertilizer (kg/ha)
1	PSAP 4 g /lit. water	27.86	3.19	24.67	14.79	9.97
2	PSAP 6 g /lit. water	29.69	1.21	28.48	14.79	13.69
3	0:52:34 4 g/lit. water	30.85	7.06	23.79	14.79	9.00
4	0:52:34 6 g/lit. water	27.93	2.21	25.72	14.79	10.93
5	Water spray (Control)	23.00	8.21	14.79	14.79	—

Table 5 : Potassium uptake(kg/ha) due to foliar sprays of fertilizers in chickpea

Tr No	Treatment	Total K uptake (kg/ha)	Contribution of Soil (kg/ha)	K Uptake due to fertilizers (kg/ha)	K Uptake from soil applied fertilizer (Kg/ha)	K uptake due to foliar spray of fertilizer (kg/ha)
1	PSAP 4 g /lit. water	135.42	33	102.42	78.31	24.11
2	PSAP 6 g /lit. water	138.81	27	111.81	78.31	33.50
3	0:52:34 4 g/lit. water	167.03	31	136.03	78.31	52.72
4	0:52:34 6 g/lit. water	126.8	40	86.80	78.31	8.49
5	Water spray (Control)	116.31	38	78.31	78.31	—

Table 6 : Effect of foliar spray of fertilizer on yield and yield contributing parameters in chickpea

Tr No	Treatment	Plant height (cm)	Numbers of pods / plant	Harvest index	Seed index (g)	Seed Yield (Kg/ha)	% Increase over control
1	PSAP 4 g /lit. water	58.67	93.67	36.12	20.0	2774	13.82%
2	PSAP 6 g /lit. water	58.67	103.0	36.73	21.67	2910	19.40%
3	0:52:34 4 g/lit. water	59.67	90.67	35.10	20.0	2611	7.13%
4	0:52:34 6 g/lit. water	58.67	95.33	35.95	20.33	2701	10.83%
5	Water spray (Control)	54.33	76.33	37.60	18.67	2437	00.0%
6	CD at 0.05%	NS	7.10				

MACS - Agharkar Research Institute, Pune, India

Absorption efficiency and physiological nutrient use efficacy of Phosphorus and Potassium applied through PSAP [PMPD] (00:40:40) & (00:52:34) in chickpea crop

Table 7 : Effect of foliar spray of fertilizer on yield and yield contributing parameters in chickpea

Tr No	Treatment	Grain yield (kg/ha)	Nutrient Uptake (kg/ha)		Physiological Nutrient Use Efficiency	
			P	K	P	K
1	RDF + PSAP 4 g /lit. water	2774	26.67	135.42	69.34	17.63
2	RDF + PSAP 6 g /lit. water	2910	28.39	138.81	70.70	21.02
3	RDF + 0:52:34 4 g/lit water	2611	30.85	167.03	22.17	3.43
4	RDF + 0:52:34 6 g/lit water	2701	27.93	126.80	53.35	25.17
5	RDF + Water spray (Control)	2437	23.00	116.31	—	—
	SE m ±	66.10				
	CD at 0.05%	203.56				

- The foliar application of the fertilizers caused differences in yield and some yield contributing characters.
- Uptake of phosphorus due to foliar application revealed that RDF + PSAP @ 4 and 6 g/l showed maximum uptake of phosphorus among the different treatments and is utilized for growth and development.
- Improved phosphorus & potassium uptake help the plants to transform acquired nutrients into economic yield as evidenced from the significant increase in the yield of PSAP treated plants.

Technology

Application of PSAP at the rate of 6 Kg per acre in three to four sprays to the sugarcane enhances cane yield by 30% with improvement of 0.5% sugar recovery in CCS unit.

PSAP IMPROVES METABOLIC CAPACITY OF PLANTS AND HELPS TO BRIDGE THE GAP BETWEEN POTENTIAL AND REALIZED YIELD

★ Most of the crops in general have genetic tolerance to diseases and pest, however, the nutrient balance, favourable soil and atmospheric conditions support luxuriant growth of crop plants.

★ The disease and pest tolerance as well as yield & quality reduces due to following three causes.

1) Imbalance in major nutrients, particularly N, P and K. Nitrogen, being a basic component of protoplasm, proteins, enzymes etc., helps to produce more vegetative growth whereas Potash works as radar while inducing various stress tolerances and Phosphate is most useful for sugar and carbohydrate synthesis and its interconversion. Phosphate is also required as energy source of various growth processes. Yield & quality is govern by P & K nutrients.

2) The balanced nutrition is require to be maintained throughout growth phases of crop ontogeny. In practice, farmers generally apply more Nitrogen and less P & K leading to succulence and poor tolerance to biological (diseases, pest), physiological (water, osmotic potential) and environmental (temperature, humidity, frost etc.) stresses.

3) Besides N, P & K micro nutrients and secondary nutrients also plays great role in crop growth, vigour and built up of tolerance to various stresses.

Due to above facts, overall crop growth is affected, crops looks unhealthy and weak which in turn get further affected due to diseases and pest. The ultimate effect is higher spending for disease and pest management, low yield and poor quality of crop produce.

The Research Organisations and Government Departments recommends balanced proportion of N, P & K. Whatever P is applied, hardly 20 to 25 % quantity is taken up by plants and remaining get fixed in the soil. K uptake is also poor. Hence, foliar spray of P & K through PSAP gives fantastic improvement in crop growth, vigour, quality & yield of sugarcane. With use of PSAP in lesser cultivation cost, farmer can get higher quality & yields.

PMPD

TECHNOLOGY

Brings transformation from climate sensitive to climate resilient system

Technology

Stress Resilient Agriculture - Mechanism and Metabolism

1. Formulated after 6 years of untiring and in depth rigorous research efforts. PSAP tried and tested on farmers' fields. PSAP technology has been proved that it spectacularly increases cane yield and improves sugarcane quality. PSAP also induces diseases, pest and various types of stress tolerance in sugarcane. Besides, this product is nontoxic, environment friendly having wide range of crops applicability. Hence can be instrumental in bringing most needed all round next agriculture revolution in the World.

2. PSAP applications are easy to handle and can be used without much changes in the agricultural practices in vogue. Applications of PSAP are flexible and can be adopted at given situation

3. Application of PSAP is complementary to the existing agricultural production technology as well as emerging technologies such as precision agriculture. Sustainable agriculture can be endorsed with PSAP.

4. PSAP is very effective in all most all the crops in improving plant health, inducing stress tolerance, higher yield (15 to 50%), quality of produce (sweetness, keeping quality, lustre). Ultimately farmers and customers are benefited.

5 By spraying 6 kg of PSAP in 4 sprays with interval of 15-20 days on 50-60 days sugarcane after emergence definitely results in ;

- ★ Cane yield improvement to the tune of 100 - 200 Quintal per acre (around 30% higher than unsprayed). This fetches additional income to cane growers. Even after deducting the cost of product and spraying cost, farmers gets B:C Ratio of Rs 1.0 : 4.0.
- ★ Overall sugar recovery increases by 0.5% which helps to improve balance sheet of sugar mills.
- ★ Per acre sugarcane yield improvement as well as sugar recovery enhancement helps to reduce cane area requirement to fulfil the crushing needs of sugar mill and also helps to increase the production of side products like ethanol about 30%, co-generation 30% (due to additional bagasse availability), bio manures etc. All this together add to the income and profit of sugar mills.

6. PSAP being eco-friendly, nontoxic and having no residual effect, the agricultural produce is very safe for human or animal or birds consumption.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

PMPD Treated Crop Plants in Biotic Stress

- Phosphorus and Potash molecule from PMPD that does not get bound to soil particles could be made available nearly fully to the plants through foliage. “P” has a key role in metabolic processes of plants & other element potash induces stress tolerance. It is well known fact that nearly 70 to 75 percent of phosphorus get fixed in soil and is not available to crop plants applied through fertilizers. Only a fraction of it, may be around 25-30% is available to plants but when depends upon local situation. To avoid the limitations of P and K based fertilizers such as; solubility, fixation, uptake, absorption & availability, new bio-active P-K of PMPD brought array of hopes after a rigorous research and development.

- PMPD induces innate defence responses of crop plants against, pests and pathogens when applied to foliage or to soil. Boosts the immune system of the plant by increased production of phenols, PR-proteins, amino acids, lignin, tannins, phytoalexins, flavonone and enzymes. Increases phospholipids but decreases nucleoside triphosphates and lipid mass per mg mycelium, resulting in increase plasma membrane, distortion of hyphae, swelling of hyphal tip and prevention of fungal attack.

- PMPD increases cell turgidity and thickness providing resistance to stress due to mineral deficiencies and climatic extremes. Once within the plant, PMPD releases phosphorus and potash, which modulates the accumulation of other nutrients through various growth stages of the plant. Increases the floral intensity, brix, TSS (total soluble solids), isoflavones, anthocyanin and fruit size. Improves the shelf life of produce. In stress energy cycle in mitochondria gets disturbed. To improve photosynthesis and re-establish cycle in cellular respiration PMPD phosphorous plays role. PMPD application to stressed and dormant crops induces uniform bud break. Early bud break enhances the chances of earlier flowering, and potentially greater harvest.

- Due to stress, disturbance is created in enzymatic activities, leading to disorder in biosynthesis at molecular level and opt for the additional supply of K to recoup enzymtic activities, while gaining the efficacy in the metabolisms K from PMPD fulfills its requirement. P and K get utilized in stress to maintain homeostasis balance much early. Split application of PMPD gain the normalcy in synthesis of primary and secondary metabolisms quickly.

- Split applications of PMPD mitigate the stress for longer period and eventually alleviates biotic and abiotic stress in growth cycle. Hence, response of PMPD treated crop plants remains uniform, increase in yield and improvement in quality. The enzyme PAL involved in phenyl propanoid biosynthesis, is activated earlier in treated plants. Lignin, one of the syntheses from this pathway also gets accumulated earlier. Lignin is believed to play an important role in defence response. Phytoalexins, or plant antibiotics, are also produced more rapidly around the infection site in PMPD treated Plant.

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

PMPD Treated Crop Plants in Biotic Stress

- PMPD inhibits the growth of fungi and quickly induces the defense response in crops. PMPD causes a number of changes in the phytopathogen metabolism, some of which leads to stimulation of the host's defense mechanism. PMPD causes phytopathogens to release elicitors, active metabolites that trigger the host's defense response.

- PMPD increases the plant's resistance to pests and insects. Treated sugarcane plants synthesize Terpenes highly volatile compounds often function as insect toxins, repel the insects and some volatiles attract insect predators.

- PMPD induces in many enzymatic activities such as phenylalanine ammonia lyase (PAL) activation, ethylene biosynthesis, lignin synthesis and phytoalexins accumulation. Ethylene is an early indicator of plant stress response and has been proposed to have the signaling function. PMPD-treated plants produce ethylene earlier than others.

- The enzyme PAL involved in phenyl propanoid synthesis is activated earlier in PMPD –treated plants. Lignin, one of the syntheses from this pathway also gets accumulated earlier. Lignin plays an important role in defense response.

- PMPD plays a complementary role in Shikimic acid pathway (SAP). which synthesizes metabolites that form the part of the plant's defense response. Phytolexins, or plant antibiotics, are also produced more rapidly around the infection site to restrict the spread of infection in PMPD-treated Plant.

- PMPD induces activity much earlier in the 6 – phosphogluconate and pentose phosphate pathway with quick accumulation of sugars. The glucose metabolism remains under normal enzymatic control in PMPD-treated plants but it completely gets disrupt within 12 hours in untreated plants, as a result of disease development.

- PMPD-treated plants regenerate bio-energy, remove the blockades and reform the cell-to-cell communication very effectively in reformation.

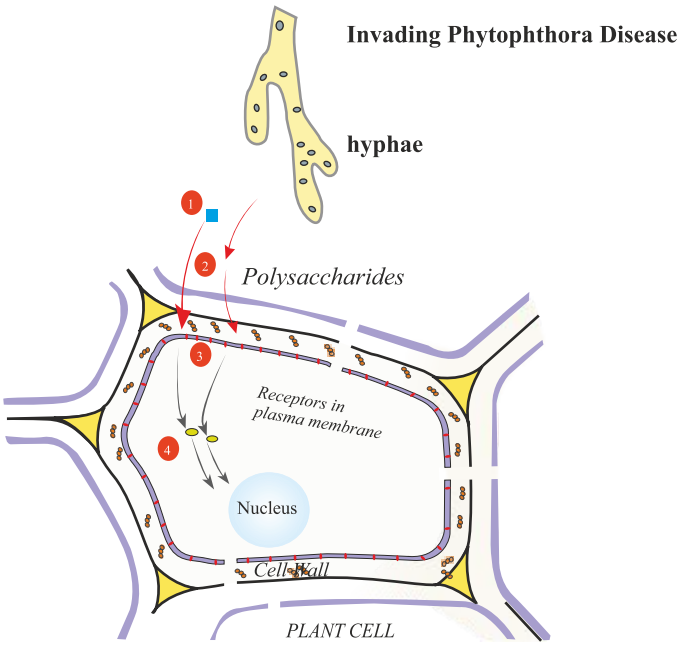
- The Potassium of PMPD plays a key role in protein and starch synthesis which helps to keep the levels of soluble sugars and amino acid under control that helps to prevent / control pest and diseases.

- The P & K synergism helps to boost oxidative phosphorylation and suppy ATP to chloroplas for photosynthesis. The P and K synergism also helps to maintain redox homeostasis.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

Plant response to pathogen in the absence of PMPD

PMPD is a systemic molecule that is mobile in both xylem and phloem. It moves from old leaves to new leaves and vice versa as well as from leaves to roots and vice versa. The action of PMPD on a pathogen is direct as well as indirect and complex.



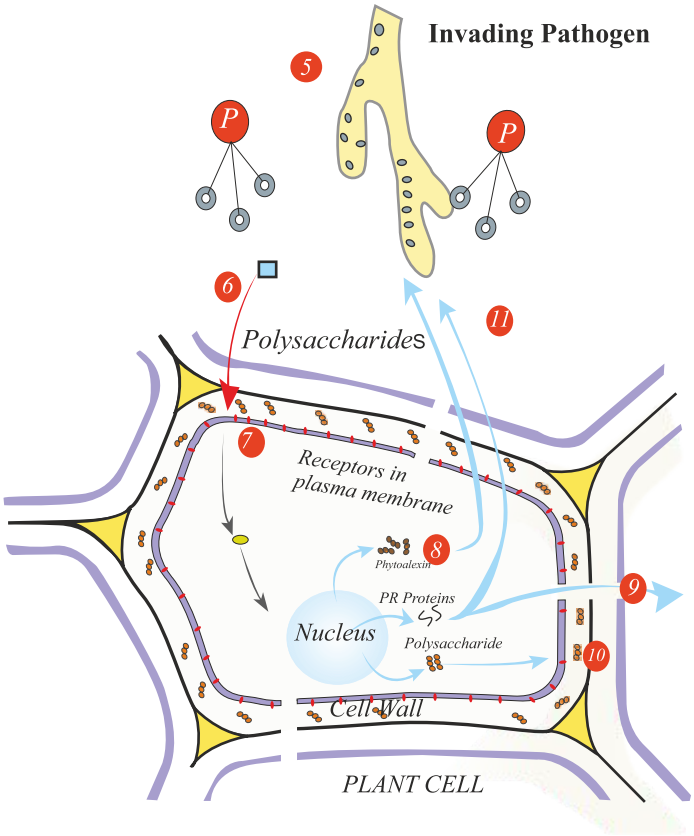
1. Some molecules from the pathogen are recognized directly but
2. Phytophthora masks this recognition with suppressors; thereafter
3. Recognition fails at the host cell interface, and
4. Only a weak signal goes to cell nucleus thereby delaying the plant response to pathogen without PMPD.

PMPD has fungistatic action, i.e. it stops the growth of the plant pathogen and inhibits the formation of spores. This causes the release of stress metabolites (chemicals) by the pathogen which are recognized by the plant as signals or as elicitors, causing the plant to enhance its defence response. One of the results of the defence response by the plant is the accumulation of phytoalexins (immune bodies); these cause an immune response similar to that in humans. In addition, hypersensitive cell death occurs (death of infected cells) as well as lignification and cell wall fortification (cell walls are thickened) take place. Lytic enzymes (which dissolve the walls of diseased cells) are also produced by the plant which, in combination with rest of the hyper-resistant response, can kill the pathogen.

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

Plant response to pathogen in the presence of PMPD



5. Pathogen is recognized by the defence system in presence of PMPD.
6. Suppressors are either under produced or not produced.
7. Recognition of the phytophathogen by plant cell.
8. PMPD encourages defensive molecules such as phytoalexins and PR proteins, and attacks the pathogen directly.
9. Defensive molecules send alarm signals to cells that have not been attacked yet.
10. Polysaccharides strengthen the cell wall adding additional protection.
11. Pathogen is limited or killed by PMPD plant response in the process.

In short, Application of PMPD enhances the activity of the plant's dynamic defence system. This induces the formation of necrotic blocking zones (dead cells limiting the spread of resultant lesion), rapid changes within the cell, production of ethylene and the death of hypersensitive cells(death of infected cells). Production of lytic enzymes, thickening of cell walls and phytoalexin accumulation in infected plants take place quickly.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

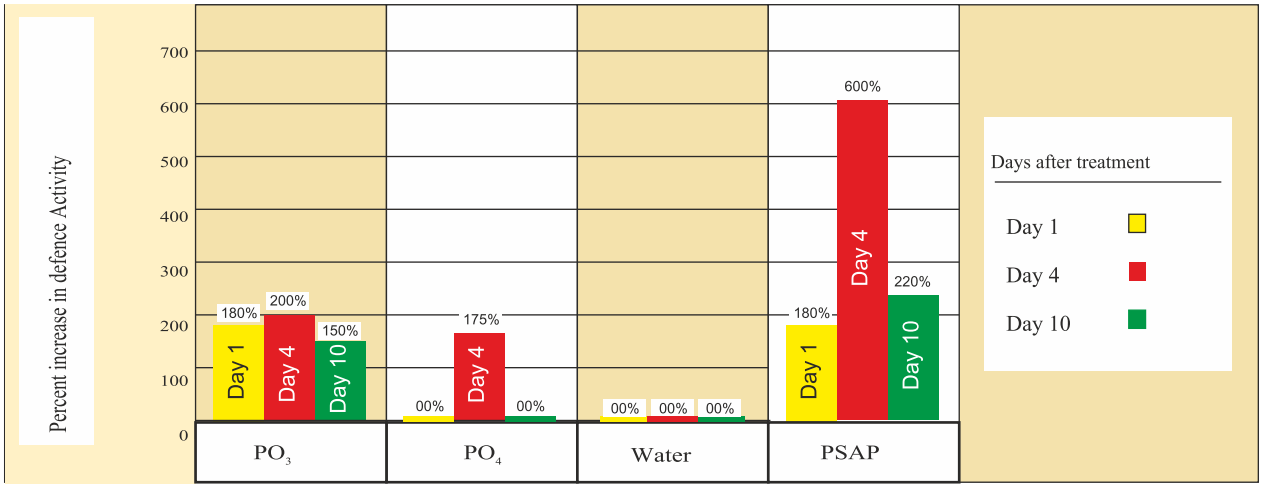
Plant Defence Response to Stress

PMPD is not only profoundly effective in regulating the Shikimic acid pathway but the mere presence of PMPD in a plant increases the production of allelopathic compounds in various pathways. These key metabolic pathways produce hundreds of compounds that are involved in fighting against pests and pathogens. Many of these compounds have a role in the management of abiotic forms of stress. Some of these compounds include,

- Lignins and tannins
- Phytoalexins
- Essential amino acid
- PR - protein
- Carbohydrates
- Cholorophyll
- Phenolic compounds
- Ethylene
- Jasmonates
- Salicyclic acid
- Auxins / cytokinins
- Abscissic acid

A hypothical comparison of three sources of phosphorus is presented in the graph with reference to the role of phosphorus in inducing a response to stress, based on our studies.

As can be seen, PMPD induces a response that is not only greater but also last longer.



Induced defense response to stress (DRS) plotted against time in percentage.

PO_3^- : Phosphite I Phosphonate : Marginal increment in DRS

PO_4^- : Phosphate : Not much increment in DRS

Water : No increment in DRS

PMPD : Fully Charged DRS with significant increment

PMPD Induced Defenses V/S Invading Organisms

PMPD induces Plant Defenses against Pathogens and Herbivores

Plants represent a rich source of nutrients for many organisms including bacteria, fungi, protists, insects, and vertebrates. Although lacking an immune system comparable to animals, plants have developed a stunning array of structural, chemical, and protein-based defenses designed to detect invading organisms and stop them before they are able to cause extensive damage.

Humans depend almost exclusively on plants for food, and plants provide many important non-food products including wood, dyes, textiles, medicines, fossil oil, cosmetics, soaps, rubber, plastics, inks, and industrial chemicals. Plants that can defend themselves from pathogens and herbivores are essential in order to protect our food supply.

Disease resistance in plants involves two distinct forms of chemical communication, pathogen recognition and defense. Both are essential components of a highly complex, multifaceted defense response, which begins with non-self-recognition through the perception of pathogen-derived signal molecules and results in the production, inter alia, of antibiotically active compounds (phytoalexins) and cell wall-reinforcing material around the infection site.

Plant Disease and Resistance

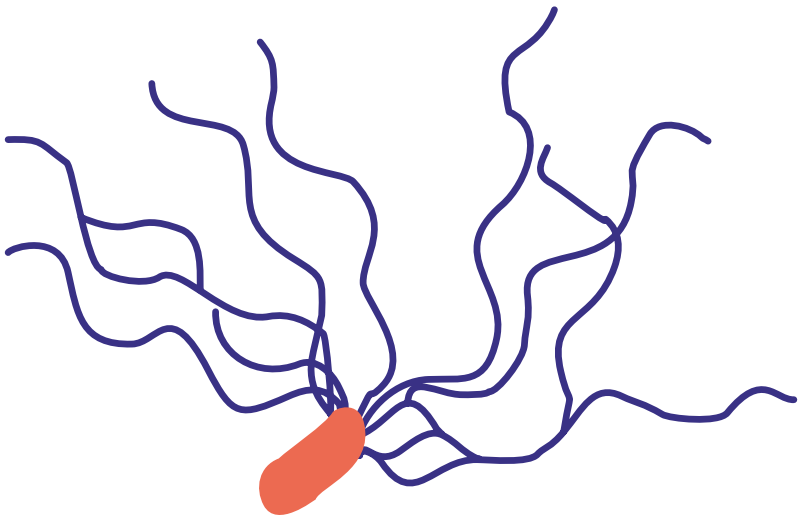
Broadly defined, disease is a physiological abnormality or a significant disruption in the "normal" health of a plant. Disease can be caused by living (biotic) agents, including fungi and bacteria, or by environmental (abiotic) factors such as nutrient deficiency, drought, lack of oxygen, excessive temperature, ultraviolet radiation, or pollution. In order to protect themselves from damage, plants have developed a wide variety of constitutive and inducible defenses. Constitutive (continuous) defenses include many preformed barriers such as cell walls, waxy epidermal cuticles, and bark.

These substances not only protect the plant from invasion but also give the plant strength and rigidity. In addition to preformed barriers, virtually all living plant, cells have the ability to detect invading pathogens and respond with inducible defense including the production of toxic chemicals, pathogen-degrading enzymes, and deliberate cell suicide. Plants often wait until pathogens are detected before producing toxic chemicals or defense-related proteins because of the high energy costs and nutrient requirements associated with their production and maintenance.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

PMPD Induced Defenses V/S Invading Organisms

Detection and Response to Microbial Pathogens



Bacterial flagella are often recognized by plants during basal resistance.

Plants have developed multiple layers of sophisticated surveillance mechanisms that recognize potentially dangerous pathogens and rapidly respond before those organisms have a chance to cause serious damage. These surveillance systems are linked to specific pre-programmed defense responses. Basal resistance, also called innate immunity, is the first line of pre-formed and inducible defense that protect plants against entire groups of pathogens. Basal resistance can be triggered when plant cells recognize microbe associated molecular patterns (MAMPs) including specific proteins, lipopolysaccharides, and cell wall components commonly found in microbes. The result is that living plant cells become fortified against attack. Non-pathogens as well as pathogens are capable of triggering basal resistance in plants due to the widespread presence of these molecular components in their cells.

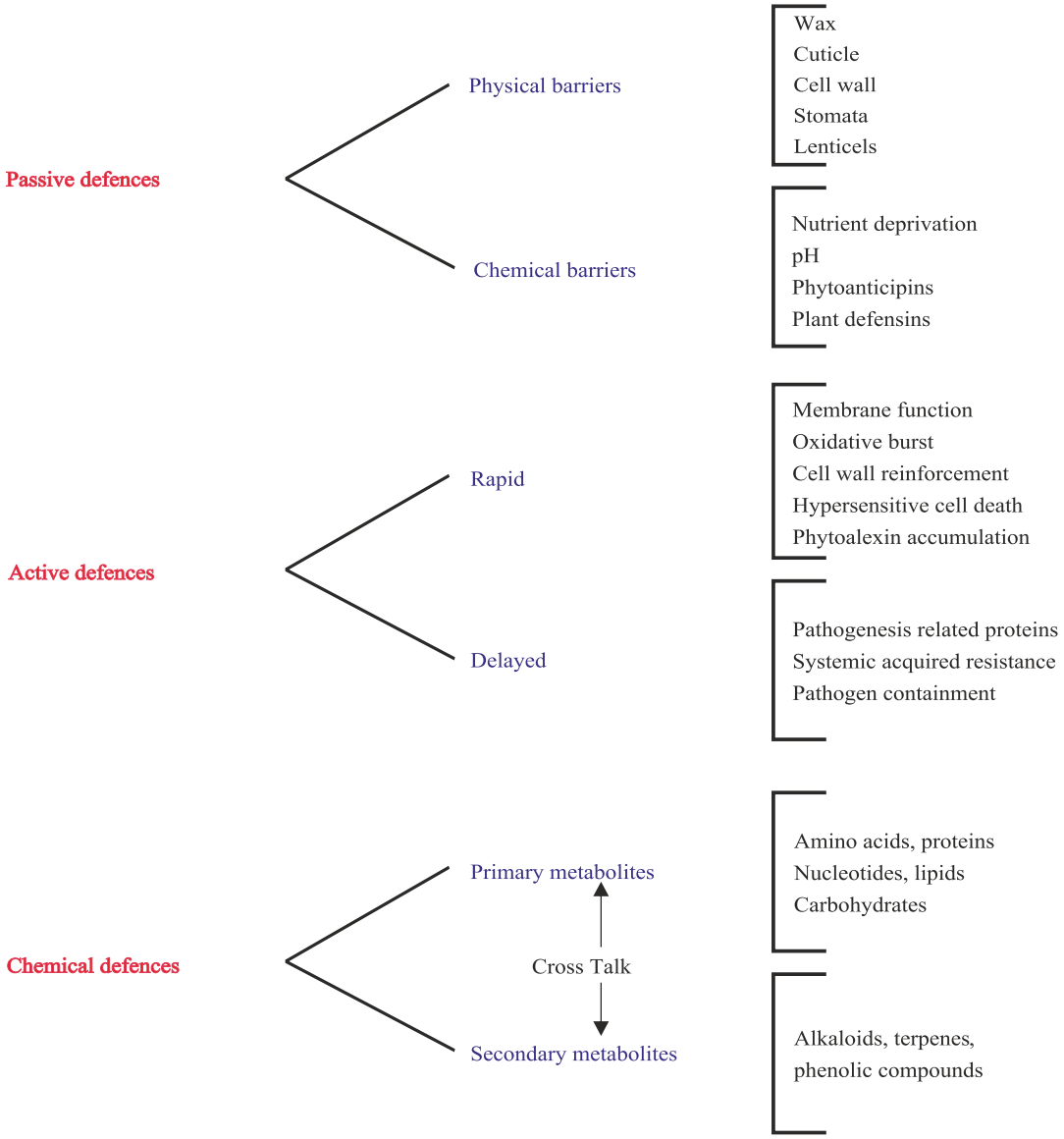
Plant dynamics and coordination of defense responses

Disease resistance mechanisms may be conveniently classified as either passive or active. Passive mechanisms include the barriers presented by the cuticle, cell wall and phytoanticipins. Active mechanisms are those activated only upon pathogen challenge and restrict the invading pathogen. Wound repair mechanisms, as cork layers, papillae, lignitubers and the expression of systemic acquired resistance retard the colonization and spread of pathogens that survive or escape the initial defense responses.

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

PMPD Induced Defenses V/S Invading Organisms



Active defense responses are most likely to be effective if they are expressed in combination. The rapid release of reactive oxygen species and the deposition of papillae, lignin and cross-linked hydroxyproline-rich glycoproteins at the point of penetration of the cell wall are followed by rapid hypersensitive cell death and phytoalexin accumulation. Lytic enzymes accumulate in intercellular spaces and vacuoles; systemic acquired resistance is activated; and wounds and tissue damage repaired. Plants use these weapons in coordination to form a potent arsenal against invading pathogens.

PMPD Induced Defenses V/S Invading Organisms

The failure or delay of these responses, invariably leads to susceptibility. Disease resistance depends on the speed, localization and magnitude of these responses.

PMPD effectively induces plant defense responses at the molecular level and hence regular application of PMPD is of immense importance.

Time	Events involved in the coordination of defence response on challenge by pathogens
Minutes	Membrane depolarization and electrolyte leakage Reactive oxygen generation Expression of genes involved in phytoalexin biosynthesis
Hours	Oxidative burst Membrane lipid peroxidation Rise in salicylic acid levels Cytoplasmic aggregation, cell collapse and hypersensitive cell death Phytoalexin accumulation Cell wall reinforcements
Days	Accumulation of pathogenesis-related proteins Systemic acquired resistance

Passive defense

To gain access to nutrients or to the replication machinery available within the host cell, pathogens must first breach the natural barriers presented by healthy plants. These barriers may be physical (the cuticle, cell wall, stomata! aperture or lenticel) or chemical including inhibitory compounds or the absence of stimulatory compounds needed for pathogen development.

Physical barriers

Structural defense

The plant cell

All plant tissues contain preformed structural barriers that help limit pathogen attachment Invasion and infection.

PMPD Induced Defenses V/S Invading Organisms

The cell wall is a major line of defense against fungal and bacterial pathogens. In PMPD-treated plants, there is an excellent structural barrier that also incorporates a wide variety of chemical defense that can be rapidly activated when the cell detects the presence of potential pathogens. All plant cells have a primary cell wall, which provides structural support and is essential for turgor pressure, and many also form a secondary cell wall that develops inside of the primary cell wall after the cell stops growing.

The primary cell wall consists mostly of cellulose, a complex polysaccharide consisting of thousands of glucose monomers linked together to form long polymer chains. These chains are bundled into fibers, also known as microfibrils, which give strength and flexibility to the wall. The cell wall may also contain two groups of branched polysaccharides: cross-linking glycans and pectins. Cross-linking glycans include hemicellulose fibers that give the wall strength via cross-linkages with cellulose. Pectins form hydrated gels that help "cement" neighboring cells together and regulate the water content of the wall. Soft-rot pathogens often target pectins for digestion using specialized enzymes that cause cells to break apart: these organisms are extremely common and anyone who has seen fruits or vegetables become brown and "mushy" has seen these pathogens in action.

Synthesis of pectins occurs more efficiently in PMPD-treated plants, and at the fruit maturity stage, pectins are translocated to seeds. Hence the occurrence of spongy tissue, a physiological disorder and a quality issue in alphonso mangoes, is reduced in PMPD-treated plants. Many cell walls also contain lignin, a heterogeneous polymer composed of phenolic compounds that give the cell rigidity. Lignin is the primary component of wood, and cell walls that become "lignified" are highly impermeable to pathogens and difficult for small insects to chew. Cutin, suberin, and waxes are fatty substances that may be deposited in either primary or secondary cell walls (or both) and outer protective tissues of the plant body, including bark.

Cell walls contain proteins and enzymes that actively work to reshape the wall during cell growth yet thicken and strengthen the wall during induced defense. When a plant cell detects the presence of a potential pathogen, enzymes catalyse an oxidative burst that produces highly reactive oxygen molecules capable of damaging the cells of invading organisms. Reactive oxygen molecules also help strengthen the cell wall by catalysing cross-linkages between cell wall polymers, and they serve as a signal to neighboring cells that an attack is under way. Plants cell also respond to microbial attack by rapidly synthesizing and depositing callose bet the cell wall and the cell membrane adjacent to

PMPD Induced Defenses V/S Invading Organisms

the invading pathogen. Callose deposits, called papillae, are polysaccharide polymers that impede cellular penetration at the site of infection, and these are often produced as part of the induced basal defense response very rapidly in PMPD-treated plants.

Some plant cells are highly specialized for plant defense. Idioblasts ("crazy cells") help protect plants against herbivory because they contain toxic chemicals or sharp crystals that tear the mouth parts of insects and mammals as they feed. There are many classes of idioblasts including pigmented cells, sclereids, crystalliferous cells and silica cells. Pigmented cells often contain bitter-tasting tannins that make plant parts undesirable as a food source.

Young red wines often contain high levels of tannins that give wine a sharp, biting taste. Sclereids are irregularly-shaped cells with thick secondary walls that are difficult to chew. The rough texture of PMPD-treated plants is caused by thousands of sclereid stone cells that can abrasively wear down the teeth of feeding animals. Stinging nettles produce stinging cells shaped like hypodermic needles that break off when disturbed and inject highly irritating toxins into herbivore tissues. Some stinging cells contain prostaglandins, hormones that amplify pain receptors in vertebrate animals and increase the sensation of pain.

Crystalliferous cells contain crystals of calcium oxalate, which are abundant in PMPD treated plants & tear mouth parts of herbivores when chewed & can be toxic if ingested.

Plant Tissues and Specialized Appendages

The epidermis constitutes the outermost protective tissue system of leaves, floral parts, fruits, seeds, stems, and roots of plants until they undergo considerable secondary growth. It is the first line of defense against invading pathogens and consists of both specialized and unspecialized cells. The epidermal cells of aerial plant parts are often covered in a waxy cuticle that not only prevents water loss from the plant, but also prevents microbial pathogens from coming into direct contact with epidermal cells and thereby limits infection. The hydrophobic nature of the cuticle also prevents water from collecting on the leaf surface, an important defense against many fungal pathogens that require standing water on the leaf surface for spore germination.

However, some fungal pathogens including Fusarium solani produce cutinases that degrade the cuticle and allow the fungi to penetrate the epidermis.

PMPD Induced Defenses V/S Invading Organisms

It is observed in PMPD-treated plants that the epidermis layer is structured to combat invading pathogens.

Chemical barriers

Proteins and Enzymes in Plant defense

Many plants and seeds contain proteins that specifically inhibit pathogen and pest enzymes by forming complexes that block active sites or alter enzyme conformations, ultimately reducing enzyme function. These proteins are generally small and rich in the amino acid cysteine. They include defensins, amylase inhibitors, lectins, and proteinase inhibitors. Unlike simple chemicals such as terpenoids, phenolics and alkaloids, proteins require a great deal of plant resources and energy to produce; consequently, many defensive proteins are only made in significant quantities after a pathogen or pest has attacked the plant provided if they have sufficient nutrients in reserve. Once activated, however, defensive proteins and enzymes effectively inhibit fungi, bacteria, nematodes, and insect herbivores.

One group of phytoanticipins, the saponins, are plant glycosides with surfactant (wetting agent) properties. Saponins bind sterols in pathogen cell membranes, destroying membrane integrity and function. In this way saponins are toxic to organisms containing sterols in their membranes. Inactive saponin precursor molecules appear to be stored in vacuoles of intact plant cells, but hydrolase enzymes released following wounding or infection convert these precursors to active, antimicrobial forms.

Several lines of evidence suggest that saponins are involved in disease resistance and host range determination.

Defensins are small cysteine-rich proteins that display broad antimicrobial activity. They are widely distributed and may be present in most plants. Defensins can be found in virtually all types of plant tissues including leaves, pods, tubers, fruit, roots, bark, and floral tissues. They exhibit a wide range of biological activities that serve to inhibit the growth of many fungi and bacteria. Some defensins also inhibit digestive proteins in herbivores.

The precise mechanisms employed by defencins in PMPD-treated plants to inhibit fungi and bacteria are required to be characterized further.

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PMPD Induced Defenses V/S Invading Organisms

Digestive enzyme inhibitors are proteins that block the normal digestion and absorption of nutrients by vertebrate and invertebrate herbivores. Alpha-amylase inhibitors are proteins commonly found in legumes that bind to amylase enzymes and inhibit starch digestion. Lectins are non-enzymatic proteins and glycoproteins that bind to carbohydrates and exhibit a wide range of functions including disruption of digestion in insects and agglutination of blood cells in vertebrates. Ricin is a powerful toxin produced in castor beans. It combines a lectin molecule with an N-glycoside hydrolase that enters animal cells and inhibits protein synthesis. Ricin is a highly potent toxin.

Protease inhibitors are typically produced in response to herbivore attack and inhibit digestive enzymes including trypsin and chymotrypsin. They occur widely in nature. Herbivore feeding often triggers a series of molecular signalling events that induce systemic production of these compounds in distal tissues that contribute to the protection of undamaged plant parts from subsequent attacks by a wide range of herbivore pests.

Hydrolytic enzymes are produced by some plants in response to pathogens and often accumulate in extracellular spaces where they degrade the cell walls of pathogenic fungi. Chitinases are enzymes that catalyse the degradation of chitin, a polymer with a backbone similar to cellulose, that is present in the cell walls of true fungi.

Glucanases are enzymes that catalyse the degradation of glycosidic linkages in glucans, a class of polymers similar to cellulose that is present in the cell walls of many oomycetes (water molds). In vitro analysis has verified the anti-fungal properties of these compounds, and transgenic plants expressing high levels of these enzymes exhibit increased resistance to a wide range of both foliar and root pathogens. Lysozymes are hydrolytic enzymes that are capable of degrading bacterial cell walls.

Active defense

Rapid

Plant responses to infection are complex and there is no universal model or sequence of events that accurately describes the dynamics of resistance. Almost every host-parasite interaction is unique in the details of the activation, localization, timing and magnitude of each component of the defense response. Resistance is rarely absolute, and whether a plant is resistant or susceptible depends on the sum of many individual responses.

PMPD Induced Defenses V/S Invading Organisms

A pattern is emerging that indicates that the outcome of many, if not all, host-parasite interactions depends on complex interactions between host and pathogen cells. These interactions are conditioned by host and pathogen gene expression, are mediated by chemical signal transduction pathways and involve dynamic interactions between elicitors, enhancers, suppressors, receptors and secondary signals. The dynamics of the interaction is sensitive to environmental fluctuations and is regulated by feedback from both the host and the pathogen. It is the complexity of plant-pathogen interactions that defines the multitude of possible outcomes.

Changes in membrane function

Most studies on the earliest stages of the host-parasite interaction conclude that the host membrane is involved in pathogen recognition and signal transduction. Membrane permeability changes rapidly following the exposure of plant cell suspension cultures to fungal and bacterial elicitors, usually leading to a loss of cellular electrolytes such as K^+ and an uptake of H^+. At the same time, there is often an influx of Ca_2^+, a key intracellular signal in plants that is involved in the activation of enzymes and gene expression. The experimental blocking of Ca_2^+ transport across membranes in inoculated bean cells also inhibits gene activation and subsequent defense responses.

The Oxidative burst

Membranes are also the sites where the oxidative burst occurs. The term 'oxidative burst' was first used to describe a rapid increase in respiration observed in neutrophils involved in the immune response of mammals. This increased level of respiration is now known to be due to the generation of reactive oxygen species, especially hydrogen peroxide and the superoxide anion (O_i), through the addition of electrons to O_2 catalysed by the membrane bound enzyme NADPH oxidoreductase. Reactive oxygen species are also produced by errors in electron transport during respiratory and photosynthetic reactions in plant cells. Cells are normally protected from the damaging effects of reactive oxygen by superoxide dismutase, various peroxidases and catalyases and by natural antioxidants such as carotenes. The rapid oxidative burst generates levels of reactive oxygen species that initiate membrane lipid peroxidation and cell death. The oxidative burst in plants is associated with the release of local and systemic signals that trigger gene expression and the oxidative cross-linking of host cell wall components. Levels of ROS accumulate at the infection court that are sufficient to kill microorganisms in vitro. Experimental suppression of the oxidative burst shows that it is involved in initiating later defense responses.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

Probable Mode of Action of PMPD

Active and Rapid Responses of Crop Plants

External attack → PMPD-treated Plant → Elicitor is detected by plant receptor

↓

Most frequently occurring defence response of plant is the hypersensitive response (HR), which occurs early during the infection process.

↓

HR involves the death of a few cells in the local region of pathogen attack to form a nacrofic lesion that may contain antimicrobial compounds.

↓

Resistance (R) genes detect the pathogen and change the membrane pressure and ion permeability of the plasma membrane. In this process, the outward K^{+} and Inward Ca^{++} and H^{+}ion flux trigger the HR.

↓

In addition to the hypersensitive response, plants can themselves defend against viruses by a variety of mechanisms including a sophisticated genetic defence system called RNA silencing. Many viruses produce double stranded RNA or DNA during replication in a host cell. Plants can recognize these foreign molecules and respond by digesting the genetic strands into useless.

↓

Deposition of lignin and production of callose, PR-protein. (Pathogens Related Proteins), reactive oxygen species (oxidative burst) such as copper amine oxidase and chitinases is the next step and called SAR (systemic acquired response).

↓

SAR is the activation of defences in uninfected parts of the plant. As a result, the entire plant is more resistant to secondary infection. SAR is long lasting and often confers broad-based resistance against different pathogens.

- Jasmonic acid biosynthesis path → J.A. induces vegetative storage Proteins
- Shikimic acid path → Salicylic acid Synthesis; Secondary metabolites production
- Ethylene production: S-adenosyl methionine → (ACC Synthase) → 1 - aminocyclopropane - 1- carboxylic acid → (ACC Oxidase) → Ethylene + CO_2 + HCN
- Sucrose, trehalose, UDP-glucose metabolism → Play role in cell wall formation and energy generation in post invasion activities. ATP and phosphate are the main components of this metabolic process.

PMPD and Cell Wall Reinforcement

Cell wall reinforcement

The first visible response to attempted penetration of plant cell walls by pathogens is often the intensification of cytoplasmic streaming followed by the accumulation of host cytoplasm under the site of attempted penetration. These cytoplasmic aggregates are thought to contain the cellular apparatus for the synthesis of cell wall fortifications. Most pathogens must penetrate host cell walls at some stage, either as germ tubes, hyphae or haustoria. If the cell can respond quickly enough to repair or reinforce the cell wall, penetration efficiency may be reduced and pathogen development retarded.

A number of different types of cell wall fortifications are produced in response to the attempted penetration of plant cell walls. Some pathogens induce the deposition of a papilla, a reinforcement composed of a branched Beta-1,3 glucan callus along with silicon, lignin and proteins, between the host cell wall and the plasma membrane, directly under the penetration peg. The rapid deposition of papillae is a common response of cereals to attempted penetration of epidermal cells by the powdery mildew fungus. Papillae in resistant cultivars form more rapidly and are more difficult to penetrate than those formed by susceptible cultivars. As a result, haustorial development is prevented. Lignitubers are lignified callose deposits that ensheath invading hyphal tips.

In PMPD-treated plants, a rapid response with timely activation of cell wall reinforcement is the more likely succeed interaction. Hydroxyproline-rich glycoproteins are structural proteins in plant cell walls involved in the organization of secondary cell wall thickening. Genes encoding hydroxryproline-rich glycoprotein biosynthesis are transcribed in advance of the invading hyphae, making cell walls tougher.

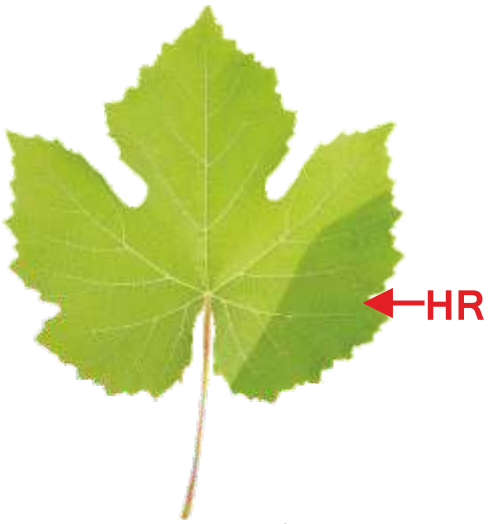
Hydrogen peroxide, released during the oxidative burst following pathogen challenge, causes extensive cross-linking between hydroxyproline-rich glycoproteins and other cell wall components, making the walls even more resistant to microbial digestion. Cross linked hydroxyproline-rich glycoproteins also provide a focus for lignin deposition on the plant cell wall. The rapid deposition of lignin and suberin following infection is associated with resistance to non-pathogens and to avirulent pathogens in many plants, including cereals, member of solanaceae, brassicas, melons and carrots.

Lignin deposited on plant cell walls ahead of invading hyphae increase their resistance to fungal penetration. Lignin also binds to hyphal tips and bacterial cells, preventing further growth and movement and restricting the diffusion of pathogen enzymes and toxins and

PMPD and Induction of Hypersensitive Response

the uptake of water and nutrients by the pathogen. Furthermore, precursor molecules and free radicals produced during lignin biosynthesis are toxic to pathogens and inactivate pathogen enzymes, toxins, elicitors or suppressors. The effect of lignin can be further enhanced by the release of reactive oxygen species and the activation of phenol oxidase enzymes that convert phenolic compounds to more toxic complex polymerized phenolics and quinones during the defense response.

Hypersensitive Response



HR lesion on leaf

Pathogens have developed counter measures able to suppress basal resistance in certain plant species. If a pathogen is capable of suppressing the basal defense, plants may respond with another line of defense namely the hypersensitive response (HR), which is characterized by deliberate suicide of plant cells at the site of infection. Although drastic compared to basal resistance, the response may limit pathogen access to water and nutrients by sacrificing a few cells in order to save the rest of the plant. The response is typically more pathogen-specific than basal resistance and is often triggered when gene products in the plant cell recognize the presence of specific disease-causing effector molecules introduced into the host by the pathogen. Bacteria, fungi, viruses, and microscopic worms called nematodes are capable of inducing the HR in plants.

Once the HR has been triggered, plant tissues may become highly resistant to a broad range of pathogens for an extended period of time. This phenomenon is called systemic acquired resistance (SAR) and represents a heightened state of readiness in which plant resources are mobilized in case of further attack.

PMPD in Pathogen Containment and Wound Repair

Recovery form Virus Infection

In addition to the hypersensitive response, plants can defend themselves against viruses by a variety of mechanisms including a sophisticated genetic defense system called RNA silencing. Many viruses produce double-stranded RNA or DNA during replication in a host cell. Plants can recognize these foreign molecules and respond by digesting the genetic strands into useless fragments and halting the infection. Plants that are infected with viruses will often exhibit chlorosis and mottling, but disease symptoms may eventually disappear if RNA silencing is successful, a process called recovery. In addition, the plant will retain a template of the digested genetic strand that can be used to quickly respond to future attack by similar viruses, a process analogous to the memory of vertebrate immune systems. In PMPD-treated plants, it is observed that recovery from viral infections was quick and lasted longer.

Active defences

Delayed

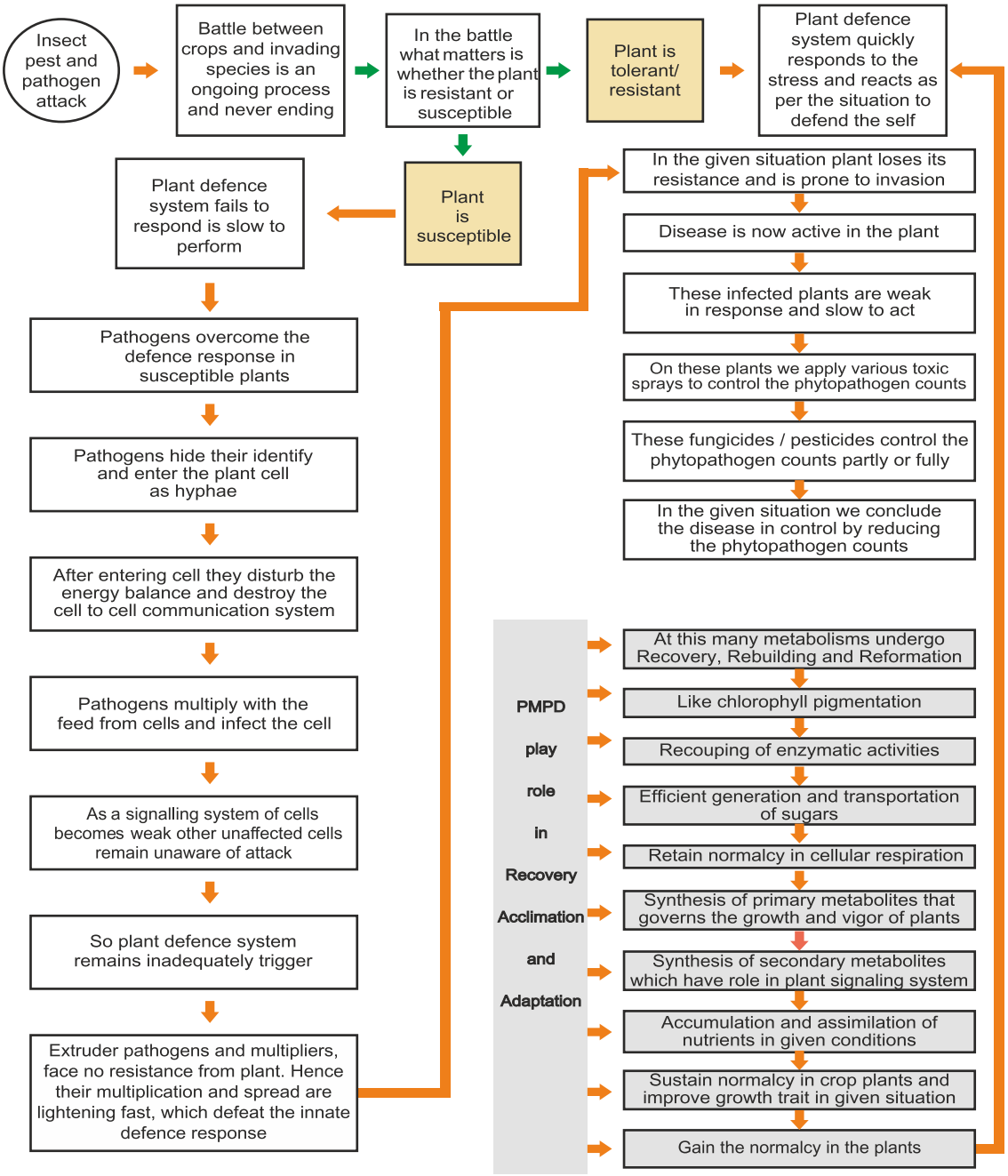
Pathogen containment and wound repair

While earlier responses retard the development of pathogens, later responses restrict their spread and contain the damage to host tissues. The ability of a plant to repair tissue damage may contribute to its ability to fight off secondary infections by opportunistic pathogens. Infected areas of fleshy tissues, roots, fruits and bark are sealed by layers of cork cells with thick, suberized walls. Wound cork is produced by a secondary meristem, the cork cambium, formed from mature parenchyma tissue in response to the damage caused by infection. In some cases, such as in the response of potato tuber tissue to the powdery scab pathogen, cork barriers appear to seal the infected area and prevent further colonization by the pathogen. Wounded tree trunks often secrete gums that effectively seal the wound from opportunistic pathogens. If pathogen growth is retarded by environmental conditions or other disease resistance mechanisms, induced barriers may also prevent further colonization by the pathogen or by secondary invaders. Tyloses are ingrowths of the protoplasts of xylem parenchyma through xylem vessel pits into the lumen of xylem vessels. They are thought to impede the progress of fungal and bacterial vascular wilt pathogens. If tyloses form rapidly enough ahead of the advancing pathogen they may restrict colonization or the spread of propagules in the xylem.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

PMPD - In Recovery, Acclimation and Adaption

The formation of tyloses involves a cost to the plant, as they not only block the spread of the pathogen but also reduce the translocation of water, possibly causing wilt symptoms. In PMPD-treated plants, recovery from such a situation is unique requiring further study.



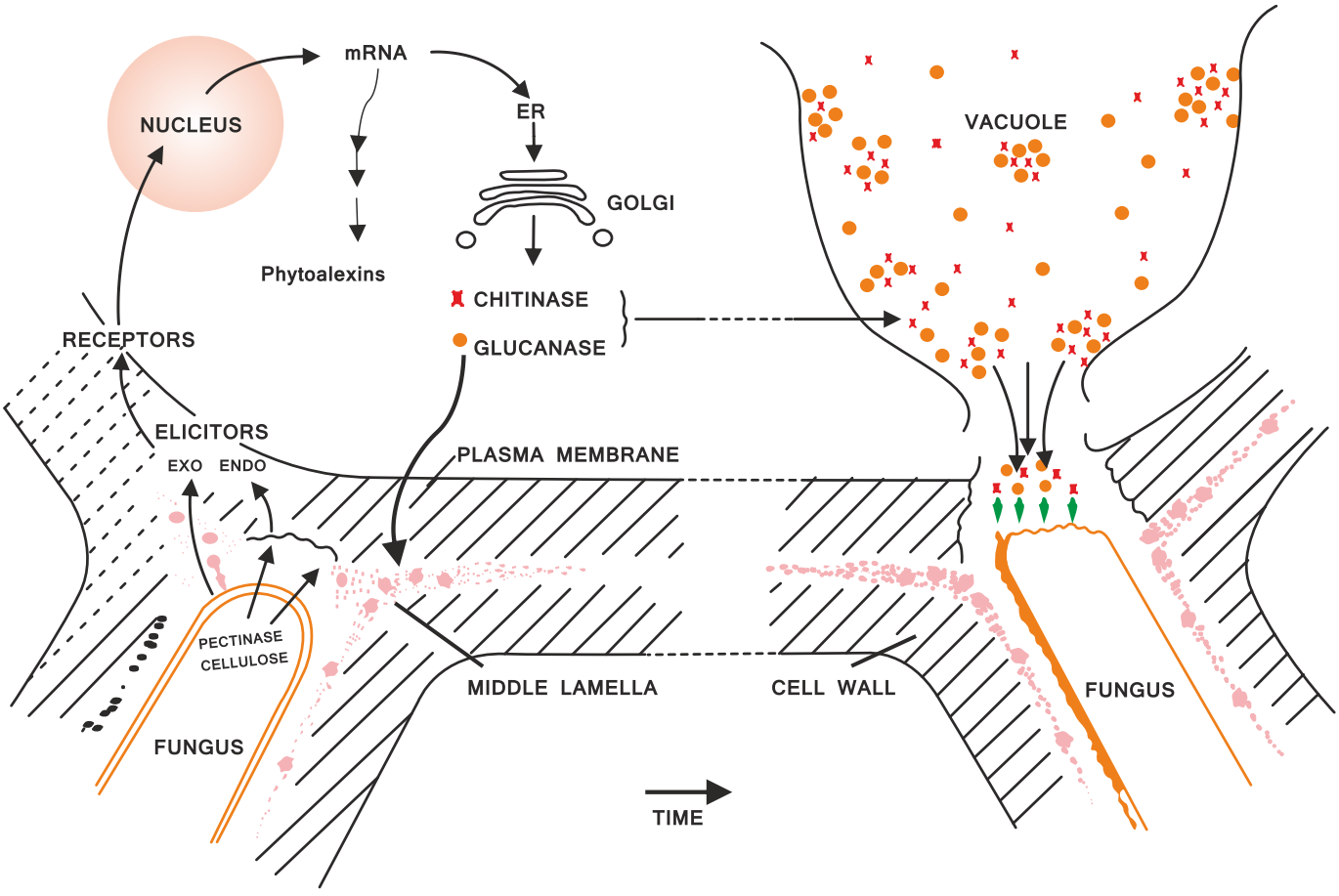
PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

PMPD in Systemic Acquired Resistance

Pathogenesis-Related Proteins (PR Proteins)

During the massive shift in cellular metabolism and gene expression, plants synthesize many novel proteins following infection. Some of these novel proteins may be enzymes involved in synthesizing phytoalexins and some may have no role in disease resistance at all. However, pathogenesis-related proteins have B-glucanase, chitinase or lysozyme activity. Some are related to plant defensins whereas others are proteinase inhibitors that disrupt pathogen nutrition. Pathogenesis-related proteins are sometimes present at low levels before infection and are induced following stress, wounding or flowering, indicating that they may have a wider function in plant growth and development than just disease rsistance.



Chitinase and Beta-1 ,3-glucanase in plant defense against pathogen attacks.

PMPD in Systemic Acquired Resistance

Chitinase and glucanase accumulate in vacuoles, although some glucanase is secreted within intercellular space. These enzymes dissolve fungal cell walls and the fragments released lead to the death of hypersensitive cells and the synthesis phytoalexins. Cellular de-compartmentalization during hypersensitive cell death ambushes the pathogen by a flood of hydrolytic enzymes released from the vacuole. Hydrolytic enzymes have antiviral, antibacterial and antifungal activity. Plants genetically transformed to overproduce glucanases, chitinases and ribozyme-inactivating proteins show about 50% reduction in disease severity. Paradoxically, some pathogens exploit the lytic activity of PR proteins to increase their virulence. Glucanases elicited by some viruses increase the porosity of plant cell walls, thus facilitating the movement of viral particles between cells. Pathogenesis related proteins accumulate over several days, reaching a maximum about seven to ten days after the initial infection. In contrast, gene-for-gene resistance is determined within hours of the initial attack. These results show that hydrolytic enzymes reduce susceptibility to disease if they are present at the time of challenge, as in plants with systemic acquired resistance, a response that protects plants against re-infection. Accumulation of PR proteins seems to be rapid in PMPD-treated plants.

Systemic Acquired Resistance (SAR)

It has been known since the early twentieth century that plants surviving an attack by a pathogen become systemically protected against subsequent infections. Systemic acquired (also called induced) resistance protects plants against a wide range of pathogens and not just the pathogen that induced the response. The expression of SAR does not make plants immune but reduces disease severity.

The development of systemic acquired resistance involves three steps:

1) The development of a slowly expanding necrotic lesion. Induction of systemic resistance may be associated with other localized responses such as hypersensitive cell death, phytoalexins accumulation, papilla deposition and lignification.

2) Systematic translocation to the phloem of a signal released two or three days after the appearance of the inducing lesion. This signal is graft-transmissible and is not specific to a cultivar, species or genus but ceases to be active once plant beings to flower. The entire signal originates from the induction site.

PMPD in Systemic Acquired Resistance

3) Primins of the rest of the plant against further pathogen challenge.
Defense responses such as the rapid release of ROS, hypersensitive cell death, phytoalexins accumulation, and enhanced levels of PR proteins are expressed more rapidly and intensely in PMPD-treated plants than in untreated plants.

The identity of the signal that triggers SAR has been the subject of intense study in PMPD treated plants. Several molecules can induce the features characteristic of SAR, including salicylic acid, B-ionone and jasmonic acid. The entire response is, however, apparently mediated by a complex signal transduction pathway regulated by a number of stress signals.Salicylic acid, a precursor of aspirin widely distributed in the plant kingdom, plays a key role in SAR. Salicylic acid binds to at least two proteins found in plant cell membranes.

One of the above two proteins shows catalase activity, which is inhibited upon binding, causing a localized build-up of hydrogen peroxide. This form of reactive oxygen causes a number of changes in plant cells that increase their resistance to pathogens. The second, high-affinity, salicylic acid-binding protein appears to activate gene expression directly. Levels of salicylic acid rise rapidly around necrotic lesions in plants and remain high in plants that have acquired resistance. Although it must be present for SAR to be expressed, salicylic acid is not translocated over long distances in plants and presumably interacts with another systemic signal.

We have learned to trigger SAR artificially by spraying plants with PMPD to alleviate stress. PMPD is gaining favour in the agricultural community because it is much less toxic to humans and wildlife than fungicides or antibiotics, and its protective effects last much longer.

Detection and Response to Insect Herbivores

Mechanical damage caused by insects is not generally considered a "true" plant disease although plants have developed surveillance systems designed to recognize insect pests and respond with specific defence mechanisms. Plants can distinguish between general wounding and insect feeding by the presence of elicitors contained in the saliva of chewing insects. In response, plants may release volatile organic compounds (VOCs), including monoterpenoids, sesquiterpenoids and homoterpenoids. These chemicals may repel harmful insects or attract beneficial predators that prey on the destructive pests. Feeding on one part of a plant can induce systemic production of these chemicals in undamaged plant tissues and, once released, these chemicals can act as signals to neighbouring plants.

PMPD and Induction of Secondary Metabolism

Feeding on one part of a plant can induce systemic production of these chemicals in undamaged plant tissues and, once released, these chemicals can act as signals to neighboring plants to begin producing similar compounds. Production of these chemicals exacts a high metabolic cost from the host plant, which is why many of these compounds are not produced in large quantities until after insects have begun to feed.

Chemical Defense

Primary and Secondary Plant Metabolites

Plant chemicals, also called plant metabolites, can be divided into two major categories: primary metabolites and secondary metabolites. Primary metabolites are substances produced by all plant cells that are directly involved in growth, development, or reproduction. Examples include sugars, proteins, amino acids, and nucleic acids. Secondary metabolites are not directly involved in growth or reproduction but they are often involved in plant defense. These compounds usually belong to one of three large chemical classes: terpenoids, phenolics, and alkaloids.

Secondary Metabolism and Metabolites

Secondary metabolism comprises a coordinate series of coupled enzymatic conversions that uses limited amounts of the products of primary or central metabolism as substrates or intermediates. Secondary metabolism uses a highly organized systematic mechanism that integrates into the developmental, morphological and biochemical regulatory patterns of the entire plant metabolic network. The inevitable link between metabolic fluxes of central metabolism and the synthesis of secondary metabolites further substantiates the existence of coordinated gene expression networks the interface of the two types of metabolism.

Accumulating evidence suggest that many transcriptional factors (TFs) coordinate the transcriptional activation of secondary metabolism genes concurrently with the expression of genes in upstream pathways of primary metabolism. For example, transketolase activity has been identified as an important determinant of photosynthetic and phenylpropanoid metabolism, and the provision of precursors by primary metabolism co-limit has been shown to the flux into the shikimate pathway and phenylpropanoid metabolism. A slight modification in transketolase activity significantly alters phenylpropanoid metabolism. There is no fixed & commonly agreed upon system for classifying secondary metabolism.

PMPD and Induction of Secondary Metabolism

However, based on their biosynthetic origins, they can be broadly divided into three main groups: terpenes, phenolics, nitrogen and sulfur containing compounds.

A number of these phytochemicals have well defined eco-physiological and defense adaptive roles in plants. More than 2,00,000 secondary metabolites are known and many more continue to be discovered: 1700 of these are known to be VOC's with high vapour pressure under normal conditions to be vapourized into the atmosphere. These volatiles are involved in a range of ecological functions, including indirect plant defense against insects, pollinator attraction, plant to plant communication and plant-pathogen interactions.

The low-molecular-weight compounds, namely nitric oxide, ethylene, jasmonic acid, methyl jasmonate, isoprene usually act as stress signals. Isoprene, nitric oxide and other compounds also directly act as antioxidants and are involved in scavenging of ROS, thermo-tolerance and adoption to environmental stress.

Alkaloids, such phenolic compounds as flavonoids, tannins, anthocyanin, coumarin, lignin, phytoalexins and terpenes and terpenoids, are phytochemical derivatives of secondary metabolism. These secondary metabolites are involved in the acetate-mevalonate, acetate-malonate and shikimic acid path.

Alkaloids: Nitrogen Compounds

Alkaloids encompass about 12,000 low-molecular-weight natural products. The principal requirement for classification as an alkaloid is the presence of a basic nitrogen atom at any position in the molecule, which does not include nitrogen in an amide or peptide bond. As implied by this exceptionally broad definition, alkaloids form a group of structurally diverse and genetically unrelated molecules. As opposed to most types of secondary metabolites the similar chemical structures of which are derived from related synthetic pathways, the many classes of alkaloids have unique origins.

Alkaloids synthesis and accumulation are associated with a variety of cell types in different plants, including epidermis, endodermis, pericycle, phloem parenchyma, phloem sieve elements and companion cells, specialized mesophyll and lacticifers. Alkaloids are commonly synthesized with amino acids as the starting precursor molecules. Alkaloids are derived from various sources and categories as tropane and nicotine, Amarryllidaceae, piperidine, indole alkaloids and benzophenanthridine although some purine-derived alkaloids are also known.

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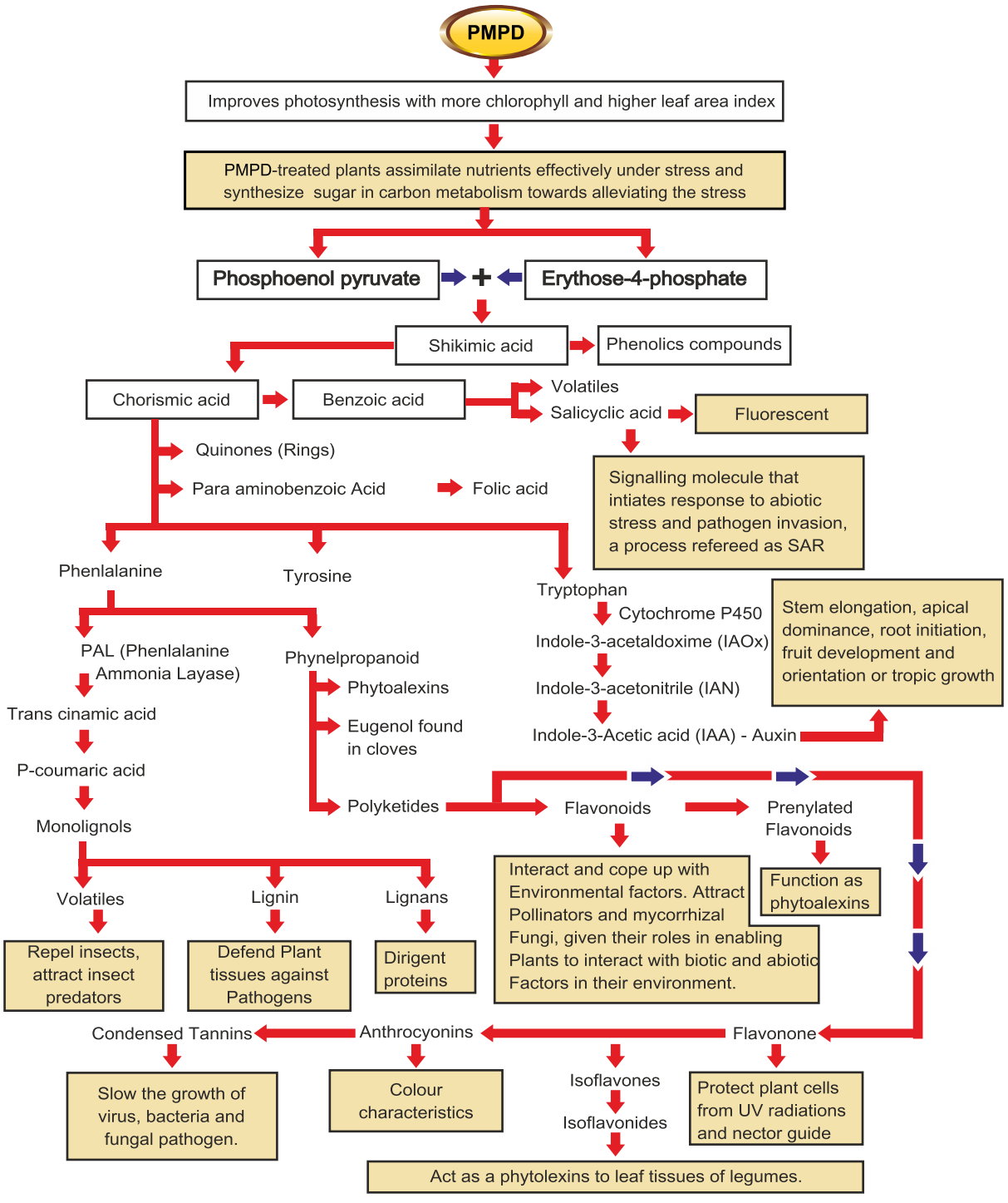
PMPD and Induction of Secondary Metabolism

PMPD in Shikimic Acid Path - Secondary Metabolism



PMPD and Induction of Secondary Metabolism

Due to the toxic nature of alkaloids, their synthesis provides a general defensive mechanism to the producing organism. For example, caffeine, cocaine, morphine and nicotine derived from amino acids aspirate, lysine, tyrosine, and tryptophan have powerful effect on animal physiology. It is toxic to both insects and fungi.

Cyanogenic glycosides are also a particularly toxic class of nitrogenous compounds that break down to produce hydrogen cyanide (HCN), a lethal chemical that halts cellular respiration in aerobic organisms. Plants that produce cyanogenic glycosides also produce enzymes that convert these compounds into hydrogen cyanide, including glycosidases and hydroxynitrile lyases, but they are stored in separate tissues or compartments within the plant; when herbivores feed on these tissues, the enzymes and substrates mix and produce the lethal hydrogen cyanide. Glucosinolates, also known as mustard oil glycosides, are sulfur-containing compounds synthesized by members of the mustard family and produce cyanide gas when broken down by enzymes called thioglucosidases. The enzyme tryptophan decarboxylase has been identified with differential expression during stress and development. It is suggested that the enzyme plays a dual role in primary and secondary defense. PMPD applications to stressed plants recoup the enzymes and restore the disrupted enzymatic activities. Alkaloids in response to biotic stress are supposed to accumulate effectively in PMPD-treated plants. The role of PMPD role in cellular respiration requires to be characterized.

Phenolics / Phenolic Componds

Phenolics are another large class of secondary metabolites produced by plants to defend themselves against pathogens. They are produced primarily via the shikimic acid and malonic acid pathways in plants, and include a wide variety of defense-related compounds including flavonoids, anthocyanins, phytoalexins, tannins, lignin, coumarin and furanocoumarins.

Flavonoids

Flavonoids are one of the largest classes of phenolics. Built upon a flavones skeleton, flavonoids are the most widespread and diverse class of low-molecular-weight phenolic compounds and are derived from a combination of the shikimic acid and the acetate pathways. Flavonoids can occur as monomers, dimers, and higher oligomers and are constituents of a variety of plant parts, including, leaves, fruits, seeds, flowers, and roots, with over 4000 different variants identified so far. Plants that produce them, flavonoids

PMPD and Induction of Secondary Metabolism

provide protection against ultraviolet radiation, invading pathogens, and herbivores. One of the ascertained functions of flavonoids in plants is their protective role against microbial invasion. Numerous flavonoids have been characterized as antifungal, antibacterial, antiviral and antioxidant are several consistent lines of evidence support the role of flavonoids in radical scavenging, chelating, and oxidant activities against various ROS.

Anthocyanins

Anthocyanins are colourful water-soluble flavonoid pigments produced by plants to protect foliage from the damaging effects of ultraviolet radiation. Anthocyanins are responsible for the showy colors of many plants and are present in high concentrations in flowers, fruits, and the leaves of deciduous plants in fall. Phytoalexins are isoflavonoids with antibiotic and antifungal properties that are produced in response to pathogen attack. These toxic molecules disrupt pathogen metabolism or cellular structure but are often pathogen specific in their toxicity. Examples include medicarpin produced by alfalfa (medicago sativa) are rishitin produced by both tomatoes and potatoes (solanacea family).

Phytoalexins

Phytoalexins are low-molecular-weight antibiotics produced by plants in response to infection. Their toxicity is non-selective and the chemical affinity of most phytoalexins for lipids suggests that they accumulate in cell membranes. For phytoalexins to play a role in disease resistance, they must accumulate to inhibitory levels at the infection court and restrict further development of the pathogen.

Since 1909, when phytoalexins were discovered, over 350 phytoalexins have been found in over 100 plant species from 30 families of dicotyledons and monocotyledons. Phytoalexins have been isolated from all parts of plants but different organs may accumulate different phytoalexins. The chemical structure of phytoalexins is diverse but, with one exception, they are small organic compounds synthesized through one of the three secondary metabolic pathways: the acetate-malonate, actetate-mevalonate, and shikimic acid pathways.

Most plant species produce several, chemically related phytoalexins, presenting a toxic cocktail to any invading pathogen. For example, many legumes synthesize phenylpropanoid phytoalexins via the shikimic acid and acetate-malonate pathways,

PMPD and Induction of Secondary Metabolism

whereas most solanaceous plants produce terpenoid phytoalexins via the acetate mevalonate pathway. French beans produce at least five phenylpropanoid phytoalexins, and potato synthesizes at least four terpenoids. Phytoalexins are believed to be synthesized in cells adjacent to the infection site in response to a signal produced either by the invading pathogen or by infected host cells and are packaged in lipid vesicles and exported to the infected cell.

Consequently, the infected cell becomes a toxic micro-environment for the invading pathogen. Phytoalexins accumulation is often associated with hypersensitive cell death. However, phytoalexins synthesis requires gene expression and the activation of complex biochemical pathways involving perhaps 20 enzymes, which must occur in living cells. Many steps in their synthesis are sensitive to regulation by the host and the pathogen.

Some plants, such as soybean and chickpea, synthesize phytoalexins upon infection, but convert a proportion into inactive sugar conjugates held in reserve in vacuoles. If the initial defense response fails to check pathogen growth, enzymes that cleave the sugar molecule are activated and the phytoalexins reserves are rapidly released. Phytoalexins synthesis is localized in cells immediately surrounding the infection court. There is no evidence that they are dispersed within the plant. In a number of interactions, resistance is lost if phytoalexins synthesis is blocked by inhibitors of enzymes involved in the synthesis and is reduced in mutants that are slow to accumulate phytoalexins.

Resistance is increased in plants transformed to express novel phytoalexins or if exogenous phytoalexins are applied. For example, although the biochemical precursor of resveratrol is widely distributed in the plant kingdom, only grapevine and peanut have the enzyme required to complete its synthesis. When the genes encoding this enzyme are transformed into tobacco, resveratrol is synthesized in response to infection.

Like other active defense responses, the success of phytoalexins accumulation depends on the speed, location and magnitude of the response. There is a good experimental correlation between resistance and rapid, localized phytoalexins accumulation in many host-parasite interactions. There is evidence that phytoalexins accumulate faster and to higher concentrations in resistant cultivars. In resistant plants, gene transcription begins within one hour of recognition, phytoalexins appear within four hours and concentrations peak to fungi toxic levels about 18-24 hours after the challenge. These events are delayed & more diffuse in susceptible plants. Phytoalexin synthesis is not universal among plants.

PMPD and Induction of Secondary Metabolism

Wheat and cucumber apparently do not produce phytoalexins, yet effectively resist most pathogenic fungi and bacteria. However, in many interactions the rapid accumulation of toxic concentrations of phytoalexins at the infection court plays a decisive role in the expression of resistance.

Tannins

Tannins are phenolic compounds that exhibit complex and highly variable chemical structures. Tannins are water-soluble flavonoid polymers produced by plants and stored in vacuoles. They are broadly categorized into hydrolysable and condensed tannins, based on whether acids or enzymes can hydrolyze the components or whether they condense the components to polymers. Tannins are the most widespread polyphenols in plants after lignin. In plants, condensed tannins may act as deterrents to feeding in reproductive tissue and developing fruit and also impart astringency to fresh fruit juices and wine. Tannins are characteristic chemical defense of plants and act as quantitative and dosage-dependent barriers to predators that may feed on plants. Due to their antibiotic, antifeedant, or biostatic effects on a variety of organisms that consume them, tannins act principally by binding to the virus and /or protein of the host cell membrane and thus arresting adsorption of the virus. Similarly, bacterial and fungal enzymes and toxic proteins may be bound by tannins and inactivated in a similar manner. This propensity to bind to proteins also presumably accounts for the fact that polyphenols inhibit virtually every enzyme that has been tested in vitro.

Polyphenols and protein complexes are essentially a surface phenomenon, maximized at or near the isoelectric point of the protein. Interactions are dynamic and the time independent; conformational flexibility in both the polyphenol and the protein is an important complementary factor that leads to strong interactions. Through their aromatic nuclei and phenolic groups, polyphenols act as multidenatate ligands on the protein surface and the efficacy of binding increases as the number of polyphenol galloyl groups increases. Tannins are toxic to insects because they bind to salivary proteins and digestive enzymes including trypsin and chymotrypsin resulting in protein inactivation. Insect herbivores that ingest high amounts of tannins fail to gain weight and may eventually die.

Lignin

Lignin is a highly branched heterogeneous polymer found principally in the secondary cell walls of plants, although primary walls can also become lignified. Lignin consists of hundreds or thousands of phenolic monomers and is a primary component of wood.

PMPD and Induction of Secondary Metabolism

Because it is insoluble, rigid, & virtually indigestible, lignin provides an excellent physical barrier to pathogen attack.

Coumarins

Coumarins are simple phenolic compounds widespread in vascular plants and appear to function in different capacities in various plant defence mechanisms against insect herbivores and fungi. Coumarins are derived through the shikimic acid pathway common to bacteria, fungi and plants but absent in animals. Coumarins are a highly active group of molecules with wide ranging of antimicrobial activity against both fungi and bacteria. These cyclic compounds behave as natural pesticidal defence compounds for plants and also are starting point for the synthesis of new derivatives with improved antifungal activity. The haloginated coumarin derivatives work very effectively in vitro to inhibit fungal growth. Some coumarin derivatives have higher antifungal activity against a range of soilborne plant pathogenic fungi and are more stable.

Furanocoumarins

Furanocoumarins are a type of coumarins that are specially phytotoxic are produced by a wide variety of plants in response to pathogen or herbivore attack. Normally these compounds are not toxic, until they are activated by light (UV-A) and go into a highenergy electronic state, which enables them to insert themselves into the double helix of DNA and to bind to the pyramidine bases, thus blocking transcription and repair, eventually leading to cell death. They may be activated very early by ultraviolet light in presence of PMPD and then can be highly toxic to certain vertebrates and invertebrates. In fact, grapefruit juice contains small quantities of furanocoumarins, which greatly increase the absorption of certain drugs into the bloodstream from the intestines. Some medicines carry warning labels cautioning people to avoid drinking grapefruit juice while taking the drugs in order to avoid an accidental overdose.

Terpenes and Terpenoids

Terpenes, one of the largest and perhaps most structurally diverse groups of the secondary metabolites, are all synthesized from two precursors, dimethylallyl pyrophosphate (DMAPP) and isopentenyl pyrophosphate (IPP). Plants invariably use the mevalonate pathway in the cytosolic compartment and the non-mevalonate pathway in plastids, an aspect that signifies sub cellular compartmentalization of the pathway.

PMPD and Induction of Secondary Metabolism

The cytosolic mevalonate pathway provides the precursor for sesquiterpenes and sterols, whereas the plastidial MEP pathway furnishes the monoterpene, diterpene and carotenoids. The chemical diversity of plant terpenoids is a reflection of their multiple biological activities in nature. In plants that produce them, isoprenoids serve numerous biochemical functions including electron transport chains, as components of membrane (sterols), sub-cellular targeting and regulation (prenylation of protein), as photosynthetic pigments (carotenoids, side chains of chlorophyll) as hormones (gibberellins, brassinosteroids, abscisic acid, cytokinins) and, as plant defense compounds and attractants for pollinators.

Monoterpenoids and sesquiterpenoids are primary components of essential oils, which are highly volatile compounds that contribute to the fragrance of plants that produce them. Essential oils often function as insect toxins and many protect against fungal and bacterial attack.

Many spices, seasonings, condiments, and perfumes are made using essential oils that function as insect toxins in plants but are relatively harmless to humans. Examples include peppermint and spearmint, basil, oregano, rosemary, sage, savory, thyme, black pepper, cinnamon and bay leaf.

Diterpenoids include gossypol, a terpenoid produced by cotton that has strong antifungal and antibacterial properties. Triterpenoids are similar in molecular structure to plant and animal sterols and steroid hormones. Phytoectysones are mimics of insect molting hormones. When produced by plants such as spinach, they disrupt larval development and increase insect mortality. The fresh scent of lemon and orange peels is the result of a class of triterpenoids known as limonoids. Azadirachtin is a very powerful limonoid isolated from neem trees. Some insects are repelled by concentrations as low as a few parts per million. Citronella is an essential oil isolated from lemon grass and contains high limonoid levels and has become a popular insect repellent. Saponins are glycosylated triterpenoids (triterpenoids with attached sugars) that are present in the cell membranes of plant species.

These substances have detergent (soap-like) properties and disrupt the cell membranes of invading fungal pathogens.However, some fungal pathogens have developed counter measures to these plant defense: Botrytis cinerea, Fusarium oxysporum, and Septoria lycopersici are all capable of degrading saponins and causing disease in susceptible saponin-producing plants.

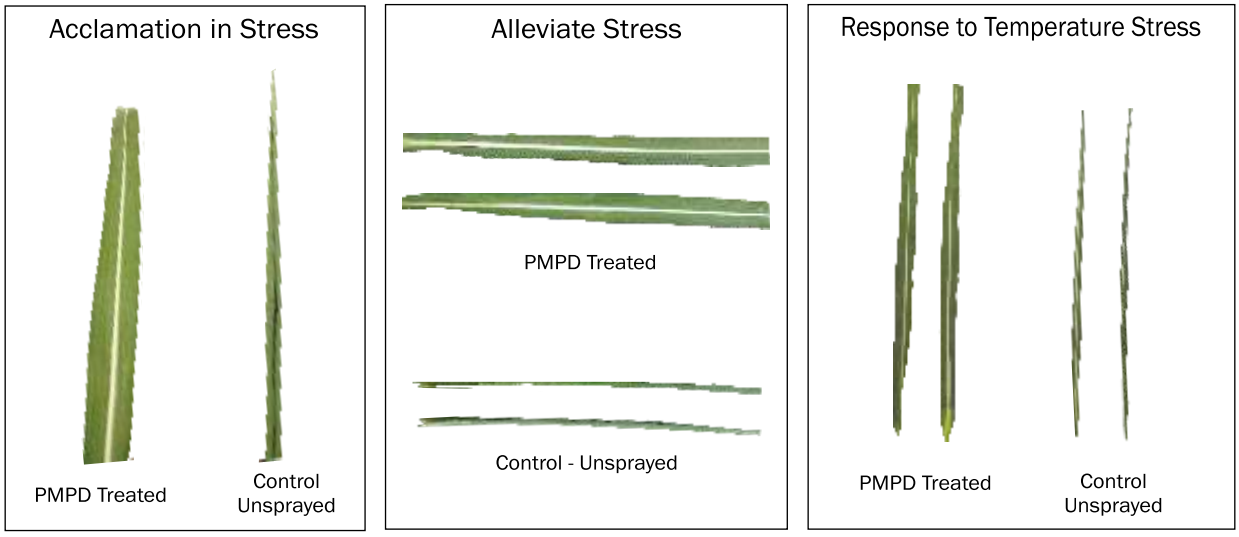
PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

PMPD Treated Crop Plants in Abiotic Stress

- PMPD influences the production process of allelopathic compounds. Once inside the plant, PMPD triggers various metabolic processes at the molecular level and is also involved in nitrogen metabolism. Storage and transport of sugars in PMPD-treated plants are very efficient.
- PMPD improves defense responses of crop plants. Regular application of PMPD can reduce stresses due to drought, nutrient deficiencies, extreme temperatures, salinity, submergence and metal toxicity. It strengthens seed vitality, improves plant stand, increases yield and improves produce quality.
- PMPD promotes plant growth. It increases photosynthesis, stimulates nutrient uptake, increases germination and boosts plan vigor. PMPD promotes plant health in general and root health in particular. It increases pre and post harvest quality.
- PMPD improves efficiency of various enzymes by regulating their activities leading to cumulative synthesis of primary and secondary metabolites.
- PMPD-treated plants recover from stress emphatically and mitigate adverse impact of changing environment.
- PMPD enhances beneficial symbioses between roots and mycorrhizal fungi. It does not support growth of phyto-pathogenic bacteria/fungi existing in the soil.
- PMPD improves yield and quality over existing traditional soil or foliar fertilizers.

Sugarcane Leaves



Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

Plants need light, water, carbon and mineral nutrients for their optimal development, growth and reproduction. Extreme conditions (below or above the optimal levels) limit plant growth and development. An unfavorable environment comprising extreme high or low temperature, salinity and drought poses a complex set of stress conditions. Plants can sense and react to stress in many ways that favour their sustenance. Plans keep in memory the past exposure to abiotic stress and even mechanisms to overcome them hence responses to repeated stress can be modified accordingly.

The most obvious effect of unfavourable conditions initially appears at the cellular level, followed by physiological symptoms. Water stress adversely affects plants physiology including photosynthesis. Prolonged water stress decreases leaf water potential and stomata! opening, reduces leaf size, suppresses root growth, reduces seed number, size, and viability, delays flowering and fruiting and limits plant growth and productivity.

Plants have evolved different mechanisms to optimize the consumption of water and manage their growth until.

They are faced with adverse conditions. Exposure to low or high light intensities diminishes physiological processes and adversely influences growth and development of plants. Excess light induces photooxidation that increases the production of highly reactive oxygen intermediates to manipulate biomolecules and enzymes. Under severe conditions, loss in plant productivity is observed. Freezing (cold) injury and high temperatures are major causes of crop loss.

Various edaphic factors such as acidity, salinity, and alkalinity contamination with pollutants and anthropogenic perturbation severely affect plant development and adversely influence crop production .

Different levels of acidic conditions influence soil nutrients adversely and limit the ease with which they are available, due to which plants become nutrient deficient and lose their normal physiological pattern of growth and development. Early exposure to salinity leads to ion toxicity within the cell followed by disruption of osmotic balance if stress is continued for longer durations. The combined effect of these ionic as well osmotic shocks alteres plant growth and development. Tolerance to salinity needs to be maintained both by osmotic and ionic homeostasis within the cells quickly. For combating salinity, plants usually try to avoid highly saline environments by keeping sensitive plant tissues away from the zone of high salinity or by exuding ions from roots or compartmentalizing ions away from the cytoplasm of physiologically active cells.

Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

Plants under extreme cold conditions survive either through avoiding super cooling of tissue water or through freezing tolerance. Certain species of plants have developed an ability to tolerate super-cooling or freezing temperatures by increasing their anti-freezing response within a short photo period, a process normally known as cold acclimation .

After sensing stress, plants exhibit an immediate and effective response to initiate a complex stress-specific signalling cascade. Synthesis of phytohormones such as abcisic acid, jasmonic acid, salicylic acid and ethylene, accumulation of phenolic acids and flavonoids, elaboration of various antioxidants and osmolytes and activation of transcription factors (Tfs), are initiated along with the expression of stress-specific genes to mount appropriate defence systems.

The most crucial aspect in mitigating stress in plants is to understand the fine-level molecular machinery and its network operative under stress conditions. This includes elaborative elucidation of the abundance of metabolic pathways and their regulatory genes in plant varieties. Identification of multigenic traits involved in stress responses, exploration of linked markers for such genes, and investigation of the probabilities to stack important genes through breeding programmes are supposed to be the focus of stress mitigation strategies.

Another supporting strategy to alleviate stress from abiotic sources in plants includes the application of PMPD. Although many of the mechanisms related to stress tolerance in plants are known, a knowledge of "on-field response" of PMPD-treated crop plants to simultaneous exposure to multiple forms of stress still needs to be explored.

Stress Mitigation Process of Crop Plants

Plants sense, manage, maintain or escape changing environmental conditions. Their perception of environmental stimuli and responses to abiotic forms of stress involves an interactive metabolic crosstalk within diverse biosynthetic networks and pathways. Root architecture is thought to be more sensitive to abiotic stimuli and reacts accordingly in soil. It is a complex phenomenon that involves dynamic and real-time changes at genetic, transcriptional, cellular, metabolic and physiological levels. The foremost and direct impact of drought, frost, salinity and heat is the creation of water-deficient conditions within cells, followed by a parallel development of biochemical, molecular and phenotypic responses to stress.

PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

In the environment, the sources of stress experienced by plants may be many and so is the complexity of their responses to multiple forms of stress in comparison to a sole source of stress. The complexity lies in modulating specific genes expression followed by metabolic reprogramming in cells in response to a given form of stress.

Tolerance or susceptibility to stress is a dynamic process involving multiple stages during plant's development. Rather than imposing an additive effect on plants, abiotic stress responses may reduce or enhance susceptibility of plants to biotic stress caused by pests or pathogens. This becomes even more important when we take into account crops because, in many agricultural systems, most crops grow in suboptimal environmental conditions that limit the genetic potential of the plants for growth and development. Defence, repair, acclimation and adaptation are the major components of resistance to stress.

Plants are vulnerable to water stress. Environmental changes such as re-watering are more frequent under the globally changing climate. Under severe water deficit peroxidation may be induced leading to negative impact on the antioxidant metabolism. Re-watering decreases the level of peroxidation further and restores growth and development of new plant parts and stomata! opening. In roots, both drought and re-watering lead to high accumulation of hydrogen peroxide ($F1_2O_2$). Drought responses vary from plant to plant in terms of the activity of superoxide d ism utase (SOD), an enzyme that plays a central role in the antioxidant metabolism. In sugarcane, SOD activity remains unaffected by drought and the expression of FeSOD and Cu/ZnSOD is down-regulated.

In Alfalfa nodules, FeSOD and Cu/ZnSOD are up-regulated by moderate drought, indicating that responses differ among species and tissues. An elevated level of salts present in the soil is detrimental to plant cells, and different cells in a tissue respond differently to the stress caused by salinity. Stressed cells, irrespective of their location, whether at the root surface or within internal tissues, influence their neighbours and cause a change in their gene expression pattern over the duration of stress .

A drastic decrease in the osmotic potential of the soil occurs due to elevated salt levels, the ultimate result of which is ion toxicity coupled with water stress in plants. This situation can affect the vitality of plants by suppressing seed germination and the growth of the seedlings, hampering senescence, and finally causing death.

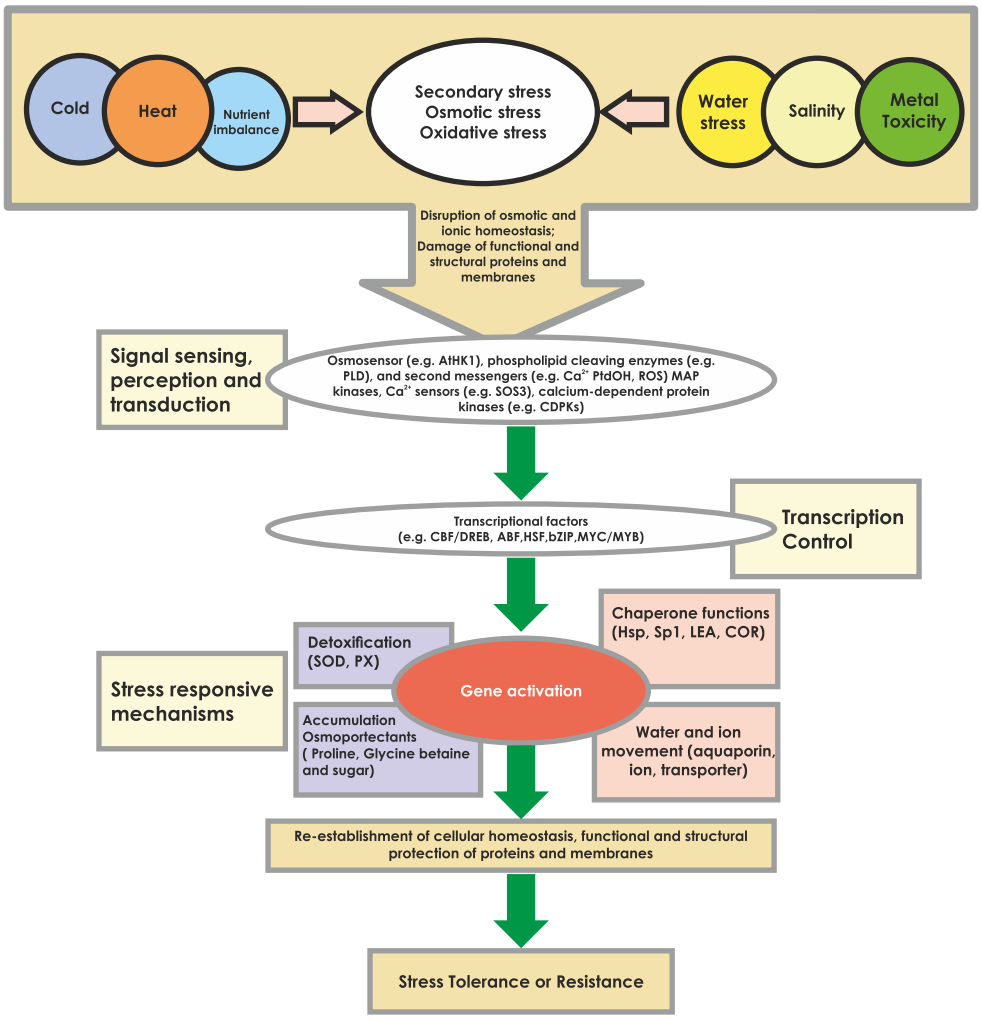
PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

The role of salt overly sensitive (SOS) stress signaling pathway consisting of three majorly involved proteins, namely SOS1, SOS2, and SOS3, is well demonstrated. Salinity conditions cause decrease in the levels of some amino acids as cysteine, arginine and methionine. Proline accumulation within cells is a well-known strategy to alleviate salinity stress. Similarly, generation of nitric oxide (NO), activation of antioxidant enzymes and compounds, modulation of hormones, accumulation of glycine betaine and polyols are some other changes within plants due to salinity stress. This principally happens because of unavailability of water and mutilation in the nutrient availability caused by high salt concentrations that create much damage to plant tissues and ultimately affect productivity.

Gene Activation and Biochemical Responses



PMPD Improves Bioefficacy of Applied PP Chemicals
Reduces Pest and Disease Incidences by Boosting Immunity

Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

The complexity of the plant's response to abiotic stress.

Primary stresses, such as drought, salinity, cold, heat and chemical pollution are often interconnected, and cause cellular damage and secondary stress, such as osmotic and oxidative stress. The initial stress signals (e.g. osmotic and ionic effects, or temperature, membrane fluidity changes) trigger the downstream signaling process and transcription controls, which activate stress-responsive mechanisms to re-establish homeostasis and protect and repair damaged proteins and membranes. Inadequate response at one or several steps in the signaling and gene activation may ultimately result in irreversible changes in cellular homeostasis and the destruction of functional and structural proteins and membranes, leading to cell death .

Some of the mechanisms that plants have evolved for adaptation to abiotic stresses

- Accumulation of osmo-protectants
- Superoxide radical scavenging mechanisms
- Exclusion or compartmentation of ions by efficient transporter and symporter systems
- Production of specific enzymes involved in regulation of plant hormones.

Due to the continued rise in global temperature, heat stress is becoming an important agricultural problem as it badly affects crop production. Rising temperature has an adverse impact on morpho-anatomical, physiological, biochemical and genetic properties in plants. A thorough understanding of physiological responses of plants to heat and mechanisms of tolerance could lead to strategic development of better approaches to crop production management.

Heat affects plants at different developmental levels, and high temperature causes reduced seed germination, loss in photosynthesis and respiration and decrease in membrane permeability. Alterations in the level of phytohormones, primary and secondary metabolites, enhancement in the expression of heat shock and related proteins and production of reactive oxygen species (ROS) are some prominent responses of plants to heat stress. Strategies to mitigate heat stress involve activation of mechanisms that support maintenance of membrane stability and induction of mitogen-activated protein kinase (MAPK) and calcium-dependent protein kinase (CDPK) cascades. Besides, scavenging of ROS, accumulation of antioxidant metabolites and compatible solutes, chaperone signalling and transcriptional modulation are certain parallel activities that help cells to sustain heat stress. Multiple stress conditions impose more beneficial impacts on plants compared to those posed by any singal source of stress.

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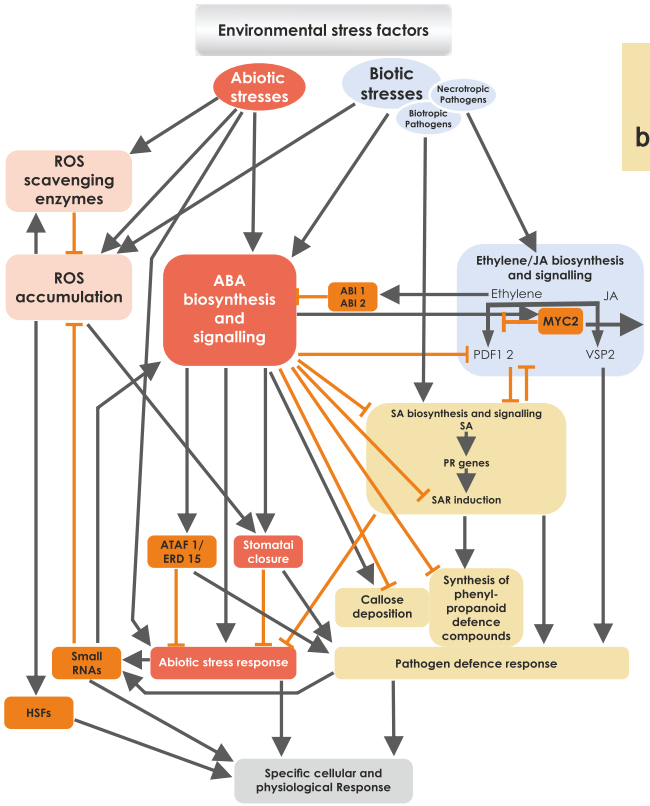
A combination different sources of stress ultimately reduces the detrimental effect of each other, thereby increasing the probability of better survival of plants. The cumulative impact of drought and accumulation of ozone (O_3) in plants results in greater tolerance. The combined effect was attributed to decreased values of stomata! conductance. Because of their elevated concentration, increased glutathione and ascorbic acid effectively scavenge ROS, thereby causing a considerable drop in total ROS content. However, it is a difficult task to elucidate the response pattern of a plant against any single form of stress, particularly when it is growing in the field and subject to the cumulative impact of different sources of environmental stress. Multiple stresses occur simultaneously in field conditions and so, multifaceted mechanisms exist in the plants to cope with rapidly fluctuating adverse situations. Phytohormones are crucial to plant growth and development but they play critical role in tolerance to abiotic stress. Gene expression profiling has revealed that prioritization of signals done by protein switches like kinases, TFs and G-proteins are mostly regulated by hormones. Plants typically channel their physiological resources to adapt to abiotic stress, which makes them more susceptible to such biotic stress as herbivory and disease attack. ABA-dependent abiotic stress response pathways are predominant.



The role of plant hormones in regulating the interaction between biotic and abiotic stress.

ROS - Reactive Oxygen Species

ABA - Abscisic Acid

JA - Jasmonic Acid

SA - Salicylic Acid

PR - Pathogenesis-related

SAR - Systematic Acquired Resistance

HSF - Heat Shock Factor

Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

Plant secondary metabolism and improved metabolite biosynthesis

Being sessile organisms, plants constantly interact with a multitude of variable and potentially damaging factors in their habitats that range from abiotic to biotic. The survival of floral diversity within an ecosystem thus requires elaborate mechanisms of defence. Among these, chemical defen ces represent the main trait of an innate immune system to cope with the hostile environment. Their metabolic plasticity evolves and exploits a range of inherent systems to create a rich repertoire of complex metabolites of adaptive significance for survival in diverse ecological niches.

These phytochemical derivatives of secondary metabolism confer a multitude of adaptive and evolutionary advantages to the producing plant. As a strategy for survival and generation of diversity at the organismic level, the ability to synthesize particular classes of secondary metabolites is often restricted to selected taxonomic groups. Apart from regulating the interaction between plants and their environment (biotic and abiotic), plant secondary metabolites also mediate certain physiological aspects of plant growth and development, symbiosis, and reproduction, and are important structural components of the wall (lignin). Secondary metabolism is the functional level of plant metabolism that is dispensable for growth and development but indispensable for the survival of the species.

The high degree of plasticity of secondary metabolism which, in contrast to primary metabolism, allows for structural and chemical modifications with almost unlimited restrictions is emphasized as a mechanical basis for the generation of chemical diversity. The diverse molecular changes that are associated with metabolism are understood to be preserved genetically, functionally and structurally to confer selective and adaptive advantages their hosts in diverse ecosystems.

A combination of gene duplication, neofunctionalization and positive selection is a mechanism for evolution of this diversity. The basis of genetic variation as being responsible for generating terrestrial organic diversity in response to plant-environment interactions has been established by research.

Despite this immense structural diversity, secondary metabolites derive their synthesis from limited products of primary metabolism. Ongoing research efforts have elucidated the basic biochemistry and molecular biology of some biosynthetic pathways of secondary metabolism, with most of the finding support that the diversification of secondary metabolism originates from elaboration of a few central intermediates.

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Induces Resistance and Builds Tolerance by Activating Stress Metabolism

Impact of Abiotic Stress and Role of PMPD in Ameliorating the Stress

Diverse abiotic stresses and the strategic defence mechanisms adapted by plants

Abiotic stress	Effects	Defence response
Salinity	Disturbed osmotic and ion homeostasis, membrane damage, nutrient imbalance	Osmolytes synthesis, stress responsive enzymes-detoxification, ion transporters
Heat	Higher transpiration, water deficiency, elevated evaporation	Induction of acclimation, synthesis of heat-shock proteins, induction of protein repair mechanisms
Drought	Decreased photosynthesis, water transport inhibition	Stomatal closure, rolling of leaves, stress-responsive enzymes, induction of osmolytes synthesis is responsible for lowering water potential
Chilling and cold	Decreased rate of biochemical reactions, decreased CO_2 fixation, ice-crystal mediated damage, free radical formation	Increased synthesis and accumulation of osmolytes, hydrophilic anti freeze proteins, termination of growth
Intense light	Inhibited photosynthesis, increased photo oxidation, elevated generation of ROS	Increased production of scavengers of ROS, inactivation of photosynthesis, oxidation of proteins and lipids etc
Heavy metals	Bio-accumulation and protein damage	Generation of reactive oxygen radicals, deposition of excess metal in vacuoles
Submergence or flood	Anaerobiosis, respiration in mitochondria inhibited	Aerenchyma development

Although the consequences of heat, drought, salinity and chilling are different, the biochemical responses seems to be more or less similar. High light intensity and heavy metal toxicity also generate similar impacts but submergence or flooding leads to degenerative responses in plants where aerenchyma are developed to cope with anaerobiosis. It is therefore clear that adaptive strategies of plants against a variety of abiotic sources of stress are analogous. This observation may provide an important key for mounting a strategic tolerance to combined sources of abiotic stress in PMPD-treated crop plants.

Plant PMPD-Empirical Interactions and Metabolic Alterations

After elucidating secondary metabolic pathways, gene regulations, enzymes involved, and factors affecting various important metabolites, accumulated evidence has made it possible to model these systems and engineer plant metabolic pathways for enhanced metabolite production. A multitude of factors, the complex integrated regulatory mechanisms and coordinated networks of metabolic routes leading to the synthesis of specific metabolites, as well as the general plasticity and adaptability of the various biosynthetic pathways, shape the profiles and fluxes of plant secondary metabolites.

Exploitation of the plant's capacity to synthesize metabolites presents numerous exciting opportunities but also equally complex challenges. Much of this rich chemical diversity arises from a limited pool of chemical scaffolds which are subsequently modified though specific chemical substitutions as catalyzed by substrate and/or regio-specific enzymes. The enzyme-driven reactivity and regio- and stereo-chemistry during the multi-step conversion of substrates into precise products in the bio-catalytic landscape of secondary metabolism is one of the lucrative key points of exploitation. The bio-mimetic exploitation of enzymes, particularly those that exhibit strict stereo specificity, is an interesting aspect in the production. Equally intriguing is the synthesis of novel metabolites by protein engineering aimed at altering the substrate specificity of biosynthetic enzymes. Application of recombinant DNA methods to restructure metabolic networks can improve the production of metabolites and proteins by altering pathway distributions and rates. Recruitment of heterologous proteins enables extension of existing pathways to obtain new chemical products, alter post transnational protein processing, and degrade recalcitrant wastes. Transgenic plants with altered enzyme activities have also become a powerful tool to study the control architecture of secondary metabolites.

The fact that the synthesis and accumulation of secondary metabolites remains under the influence of the environment adds to the multiple dimensions of the metabolic manipulation level points for enhanced production, which seems to be very effective in PMPD-treated crop plants. Following this direct logic, varied levels of metabolic perturbation through manipulation of environmental factors, either singly or in combination, have been reported to trigger positive abrupt activation of qualitative and quantitative changes in the accumulation of secondary metabolite in plants.

Understanding the physiology of the pathway is as essential, as understanding transport, pH and cellular and subcellular compartmentation. Genomic sequencing of the target plant species using proteomics and metabolomics as tools for linking the genes with the

Plant PMPD-Empirical Interactions and Metabolic Alterations

secondary metabolite pathways would be a useful and promising approach to obtain deeper insights into the stress-mitigating mechanisms in PMPD-treated crop plants and to deploy them to increase productivity. Studying the alleviation of abiotic stress in PMPD-treated field-grown plants will open new gateways for scientists to unearth novel strategies to mitigate such stress. Study of omics may help in understanding these complex PMPD-plant interactions and metabolic alterzations.

Genomic and biochemical approaches and an appreciation of molecular evolution and environmental influences, as well as structural enzymology, hold great promise for altering the complex plant secondary metabolic pathways towards synthesis and accumulation of desired bioactive compounds. These are required to be established in PMPD-treated crop plants. However, the regulatory architectures of these pathways, and the ways in which these are integrated into broader metabolic networks, are less well understood, often making it hard to predict the results of over expressing a single gene or multiple genes within a particular pathway. Several attempts to dissect secondary metabolism for the purpose of improving bioactive metabolites using classical genetics have yielded, to some extent and in some species, positive results. It must also be tried in PMPD-treated crop plants. Understanding the basic network of metabolic intermediates and enzyme forms the fundamental basis of unrevealing these attributes. Knowledge of the spatial and temporal regulatory architectures of secondary metabolic pathways, and the ways in which they are integrated into broader metabolic networks is the key for establishing the mode of action of PMPD at molecular level.

Transcription factors, a diverse group of proteins that recognize specific DNA sequences in the promoter of genes, negotiate the regulation of gene expression at the level of transcription. TFs mediate the assembly of the basal transcription machinery resulting in the activation of RNA polymerase II and mRNA synthesis. The control of specific sets of genes within the metabolic network is accomplished by the interaction among TFs, between TFs and non-DNA-binding proteins and between TFs and cis-regulatory elements in organized hierarchical gene regulatory networks. Empirical observations on PMPD-treated crop plants and data show that there is a great potential for a broad range of applications, ranging from improving the production of certain secondary metabolites to revealing new pathways in plants.

For further developing the full potential of metabolic engineering, it is thus necessary to increase our knowledge about plant secondary metabolism at the level of the intermediates, enzymes and genes in PMPD-treated plants.

PMPD Improves Photosynthesis in Temperature Strees

Extreme Temperatures

At higher temperature K helps to synthesize heat shock proteins (hsps) and scavenging ROS. The synergism of P & K from PMPD helps to activate CDPK (calcium dependent protein kinase) and MAPK (mitogen activated protein kinase) critical components of abiotic stress defense. K also helps to improve nitrogen use efficiency.

Cold Stress

Sugarcane responds to chilling temperatures with dramatic alterations in photosynthesis, which is by far the most explored process in sugarcane for obvious reasons. The dynamics of soil P & K changes during plant growth and PMPD fulfils the timely physiological demands. Unlike N & P which are the essential component of biomolecules, adequate K is essential for regulating essential physiological processes and stress mitigating strategies.

Under frezing tolerance K from PMPD helps to induce synthesis of glycosylated antifreeze proteins and saturated fatty acids to overcome freezing induced dehydration

For instance, under chilling temperatures, the rate of photosynthesis is severely decreased. Furthermore, earlier studies carried out on leaves of a cold-sensitive cultivar revealed that important photosynthetic enzymes affected by chilling temperatures (10°C) include sucrose phosphate synthase, NADP-malate dehydrogenase and pyruvate orthophosphate dikinase, indicating a fundamental role of these enzymes in sugarcane subjected to low temperatures. It was also observed that chilling temperatures increased aspartate and alanine levels in the leaves of the sugarcane plants.

The protective mechanisms in PMPD-treated sugarcane plants against chilling injury well be dependent on a complex antioxidant system. So far, the expression profiles of cold-inducible genes have revealed proteins that are directly involved in chilling and freezing tolerance. For instance, one sugarcane EST encoding a putative xanthine dehydrogenase (XDH) was significantly induced after exposure to cold. XDH is a gene encoding a putative NAD-dependent dehydrogenase that involved in protection against oxidative stress due to such exposure.

High Temperature Stress

On the other hand, markedly higher temperatures also seem to affect sugarcane development in various ways. For example, sugarcane grown under high temperatures (40°C) showed a significant decline in shoot dry mass, increased tillering, early senescence and smaller internodes, probably due to a reduction in carbon partitioned to stored sucrose.

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

PMPD Improves Photosynthesis in Temperature Strees

High Temperature Stress

Leaves Showing Temperature Stress

Photosynthesis Activity Reduced

Furthermore, it has been shown that elevated temperature affects metabolic pathways mainly through oxidative damage to cells, thereby affecting the levels of both primary and secondary metabolites.

For example, the synthesis of free proline, glycinebetaine, soluble sugars, carotenoids and flavonoids was shown to be enhanced after heat-stress (40 °C), and such changes in metabolite levels were crucial to improving heat tolerance of sugarcane.

It is noted, using biophysical and biochemical approaches, that in sugarcane the effects of heat stress are reversible through small heat-shock proteins (sHsp), which constitute an important chaperone family. This indicates a mechanism to compensate for the damage caused by high-temperature stress, thereby pointing to a potential source of improved tolerance to heat stress.

Thus global increase in ambient temperature will be a critical factor for plant growth in the future. Renewed scientific interest will hopefully lead to a better understanding of the physiological responses of treated plants to high temperatures, mechanisms of heat tolerance.

PMPD Improves Water Stress Tolerance

Water Deficit Stress

Sugarcane is grown in almost all tropical and subtropical areas of the globe, including regions where water availability is limited or highly variable. Additionally, an increase in the frequency of a different kind of El Nino, which is characterized by an anomalous increase in sea surface temperature (SST) in the central tropical pacific, flanked by colder regions in the west and east, may alter the distribution pattern of precipitation in important sugarcane-producing countries such as Australia, Brazil, India and China.

Under water deficit K from PMPD activates the accumulation of osmolytes and helps to induce antioxidative enzymes to counter the damaging effect of ROS (Reactive Oxygen Species) on biomolecules and membrane damage. The active P of PMPD helps to meet critical demand of the MAP kinases (Mitogen Activated Protein)to induce transcriptional regulation. PMPD-treated sugarcane plants respond to drought is fundamental to improve crop management and water use efficiency and thus ensuring the viability of sugarcane cultivation. The first response of a plant to water deficit is reduction in growth. As the plant water potential decreases, photosynthetic rate also decreases. A key priority is to understand the biochemical changes that occur in photosynthesis when sugarcane is exposed to drought stress. Some preliminary studies showed decreased activity of such enzymes such as ribulose 1,5-bisphosphate carboxylase (Rubisco), phosphoenol-pyruvate carboxylase (PEPC), NADP malic enzyme (NADP-ME) and PPDK, with the decline in leaf water potential, the impact of drought being more prominent on PPDK activity. Sugarcane is a C_4 plant and as such has a CO_2-concentrating mechanism, which provides, among other advantages, a reduction in photorespiration and higher water use efficiency when compared to C_3 plant species. There is evidence that sugarcane utilizes two distinct forms of C_4 metabolism, identified by the decarboxylation enzymes used: (NADP-ME) and phosphoenolpyruvate carboxy kinase (PEPCK), with PEPCK decarboxylation predominating over NADP-ME.

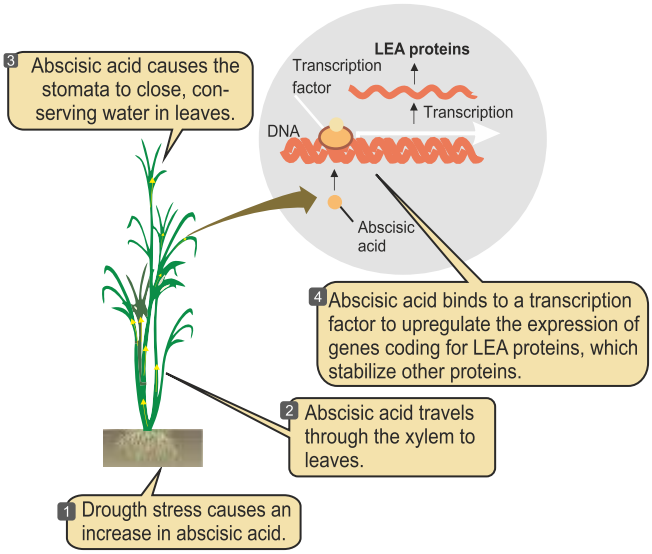
During drought stress, plants usually have a lower carbon assimilation rate, which provides an insufficient sink for electrons generated in the electron transport chain (ETC) and consequently leads to overproduction of ROS. Up-regulation of genes encoding for polyamine oxidase, cytochrome-c-oxidase, S-adenosylmethionine (SAM), decarboxylase and thioredoxins, which directly or indirectly participate in the regulation of intracellular redox status, has been demonstrated in sugarcane under drought stress and may contribute to the plants tolerance to water deficit. In a similar manner to catalase (CAT), this enzyme is responsible for the reduction of H_2O_2 to H_2O and O_2, and a decline in peroxidase activity is considered a limiting step to ROS neutralization in sugarcane. The accumulation of the osmolytes trehalose and proline also contributes to the reduction in the damage caused by the accumulation of ROS and is associated with drought tolerance in sugarcane. Another point that deserves attention is the response mediated by ABA, the

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

PMPD Improves Water Stress Tolerance

plant hormone related to water stress signaling and regulating water balance.



Drought responses in sugarcane were found to be analogous to those induced by exogenous ABA application. Both drought and ABA induced the expression of genes encoding a PP2C-like protein phosphatase, a S-adenosylmethionine decarboxylase and two delta-12 oleated esaturases. It is also reported that SodERF3, a sugarcane ERF, (ethylene responsive factor) is induced by ABA under drought stress, and the factor may also be involved in salt and drought tolerance. However, plant response to drought is a complex phenomenon, especially with a polyploid genome like sugarcane, besides the fact that drought stress involves biochemical networks that are still being elucidated. For example, phosphorus and potash supply through PMPD improved the acclimation capacity of sugarcane by affecting plant characteristics related to water status and photosynthetic performance and causing network modulation under water deficit.

Guangxi Academy of Agricultural Sciences – China : Reported in ACS OMEGA Journal published by American Chemical Society, Role of PMPD in mitigating water stress: improvement of photosynthetic activities, growth & vigour of PMPD treated cane in stress.

The results revealed that the PMPD application is an efficient technique for improving the tolerance of sugarcane plants subjected to limited water irrigation (50% of reduction in require water). It also up-regulated the photosynthetic capacity by protecting the negative impacts of sugarcane plants during limited irrigation. Taken together, PMPD has a significant role in sugarcane cultivation under insufficient water availability for irrigation and its optimum dose will be supportive in mitigation of limited irrigation in a variety of crops for sugar and bio-energy sectors. The combination of P & K also greatly improved the photosynthetic activities and plant growth.

PMPD and Water logging Acclimation

Water-log Stress

Under the current scenario of climate change, water-logging is one of the major abiotic constraints in crop cultivation with more frequent prediction of heavy rainfall. The extent of injury due to water-logging depends upon genotypes, environmental conditions, stage of development and duration of exposure. Improved understanding of the physiological responses can help to develop strategies for sustainable sugarcane yield. Nutrient deficiency is the major cause of poor plant growth in waterlogged soil. Inhibition of aerobic respiration during water-logging limits energy metabolism which restricts growth and different developmental processes. The acquisition of soil nutrients (uptake and translocation) is severely affected due to deficiency of ATP on account of inhibition of aerobic respiration and reduction of redox potential due deficiency of O_2. Plants that are deprived of oxygen rely on anaerobic metabolism like glycolysis and alcoholic fermentation to maintain adequate ATP production. In sugarcane oxygen deficiency up-regulates anaerobic polypeptides termed as ANPs viz. some enzymes Pyruvate decarboxylase(PDC), Aldehyde dehydrogenase(ADH) & Sucrose Synthase(SuSy).The expression and synthesis of these ANPs requires demand of Phosphorus and Potassium and other micronutrients. A Possible role of pyrophosphate(ppi) as high energy donor molecule that can substitute role of ATP has been suggested in sugarcane. The phosphorus and potassium dynamics is altered under waterlogged condition causing reduced uptake of P and K. The timely foliar application of PMPD synchronizes the crop demand. The phosphorus (P) acts as a fuel molecule for converting light energy to chemical energy and potassium helps to activate oxidative phosphorylation and specific enzymes and proteins. Water logging is a widespread phenomenon that drastically reduces cane yield by 40-80%. Exogenous application P and K has been reported to effectively ameliorate the adverse effects of water-logging. K supplement under water logging increases growth, photosynthetic pigments and photosynthetic efficiency.

Under water-logging it is not just the presence of unique genes in tolerant species that facilitates the survival but instead some specific regulation at 'omics' level is involved. The light exposure of plants can reduce the need of fermentation, so a successful shift of metabolism in favor of energy metabolism is important. P & K from PMPD helps to improve photosynthesis and radiation use efficiency to produce ATP. Nitrite -dependent ATP production and regulation of NO increases ATP/ADP ratio. PMPD-Potassium activates nitrate reductase(NR) and cause accumulation of nitrite. The NO can defuse out of mitochondria and NO to nitrite conversion which helps to maintain NAD^+/ $NADP^+$ levels which is important for ATP synthesis. In water logging tolerant crops nitrite dependent ATP production is sustained for longer period.

Hypoxia/anoxia induced damage to roots limits nutrient uptake and therefore foliar PMPD application is recommended to ameliorating water logging tolerance. Combined

PMPD and Excess Nutrients Tolerance

Water-log Stress

application of P and K in the form of bio - active nutrients provide fuel for improving radiation use efficiency and activating different enzymes such as kinases and regulating metabolic processes through regulatory metabolites such as NO and H_2O_2.

UPCSR-GSSBRI, Seorahi from 2016 to 2018

Tested the impact of split application of PMPD for two years in water logging situation at Eastern Uttar Pradesh and reported 24.4 tons/ha increased in sugarcane yield and recovery improvement of 0.5% in CCS.

Toxic Metal Stress

The contamination of water, soil and sediments with toxic metals has been and will continue to be a major environmental problem that needs to be dealt with. Nowadays, it is being realized that apart from the intensive programmes and continuous efforts in plant breeding to increase sugarcane productivity, it is also necessary to deal with pollution caused by contaminated water, pesticides, fertilizers, sewage sludge, industrial residues and herbicides, which contain different concentrations of toxic metals. These metals can be taken up by the growing sugarcane, severely affecting plant development. In the past few years, a number of reports have focused on the effects of toxic metals on a wide range of plant species.

In one study, high concentrations of zinc (65 and 130 ppm) were shown to increase lipid peroxidation in sugarcane, thereby affecting membrane integrity of leaves, root growth and mitotic efficiency. The interference of Zn in normal mitosis could be related to inhibition of DNA synthesis. Moreover, excess Zn increased the content of photosynthetic pigments in leaf tissues of sugarcane, which could be related to a disturbed synthesis of proteins and nucleic acids. In metal stress due to excess cadmium, the antioxidant enzymes of sugarcane seedlings were affected in different ways showing a decrease in CAT activity and an increase in glutathione redutase (GR). Aluminum is a very commonly occurring metal and, due to its worldwide distribution in soils and in the earth's crust, deserves special attention, particularly if sugarcane is cultivated in Al-contaminated soils. When Al toxicity is considered, the compatible solutes trehalose, glycinebetaine and proline can be indicators of the interaction between drought and acidity stress in soil.

However, PMPD treated sugarcane perform better in any kind of soil. More comprehensive view has to be taken and must necessarily include studies on gene expression, protein translation and enzyme activity associated with nutrient uptake and mental tolerance.

PMPD and Excess Nutrients Tolerance

Nutrient Stress

Nutrient status is an environmental factor that can influence growth rate, number of green leaves per mother shoot, leaf area and tiller density of sugarcane. Therefore, nutrient imbalance is one of the oldest subjects in sugarcane science. Ion stress caused by excess aluminum (Al) and iron (FE) on sugarcane could be alleviated with additions of phosphorus (P) and potassium (K) instantly made available with application of PMPD. Hence the necessity of having adequate K available to utilize unassimilated nitrogen (N) in sugarcane to bring about a stage of maturity where the reducing sugars are converted to sucrose. Nutrient deficiency is detrimental of sugarcane growth and development and can reduce yields, a phenomenon that continues to be the subject of extensive research. The quantum yield for CO2 uptake decreased linearly with decreasing leaf nitrogen (N) content and the rate of photosynthesis decreased with increased severity of K deficiency.

Therefore, the application of PMPD along with K fertilizers to a soil deficient in K could improve sucrose recovery through the reduction in fiber content. It has been shown that balanced use of all the needed nutrients can help in improving cane productivity and enhance sugar recovery by making the plant resistant to abiotic as well as biotic form of stress, and through better synthesis and storage of sugar. For example, P supply alleviated the negative effects of water deficit on sugarcane photosynthesis, possibly by increasing proline content. Although drought-tolerant sugarcane genotypes exhibited higher free proline content than drought-sensitive plants, however responses are more efficiently modulated by PMPD in sugarcane. Another example of resistance to abiotic form of stress is, P, K and Si-enhanced salt tolerance in salt-sensitive sugarcane genotypes resulting in decreased Na+ concentration and increased K+ with improvement in K+/Na+ ratio. It is also interesting to note that the application of PMPD at the time of planting sugarcane under water stress significantly increased the stomatal diffusive resistance, thereby decreasing transpiration rate and increasing the leaf water potential, cane length, sucrose content of the juice and sugarcane yield.

Excess Nutrients Trigger Extreme Stress Responses

Stress responses to both deficiency and excess of nutrients appear to involve complex mechanisms that modulate the uptake and accumulation of ions. Therefore, identifying and understanding, in PMPD-treated sugarcane plants, the expression of genes responsible for or associated with nutrient uptake and distribution may lead to efficient nutrient management in sugarcane, controlling the application of fertilizers to sugarcane crops and consequently the environmental impact of fertilizer production and application.

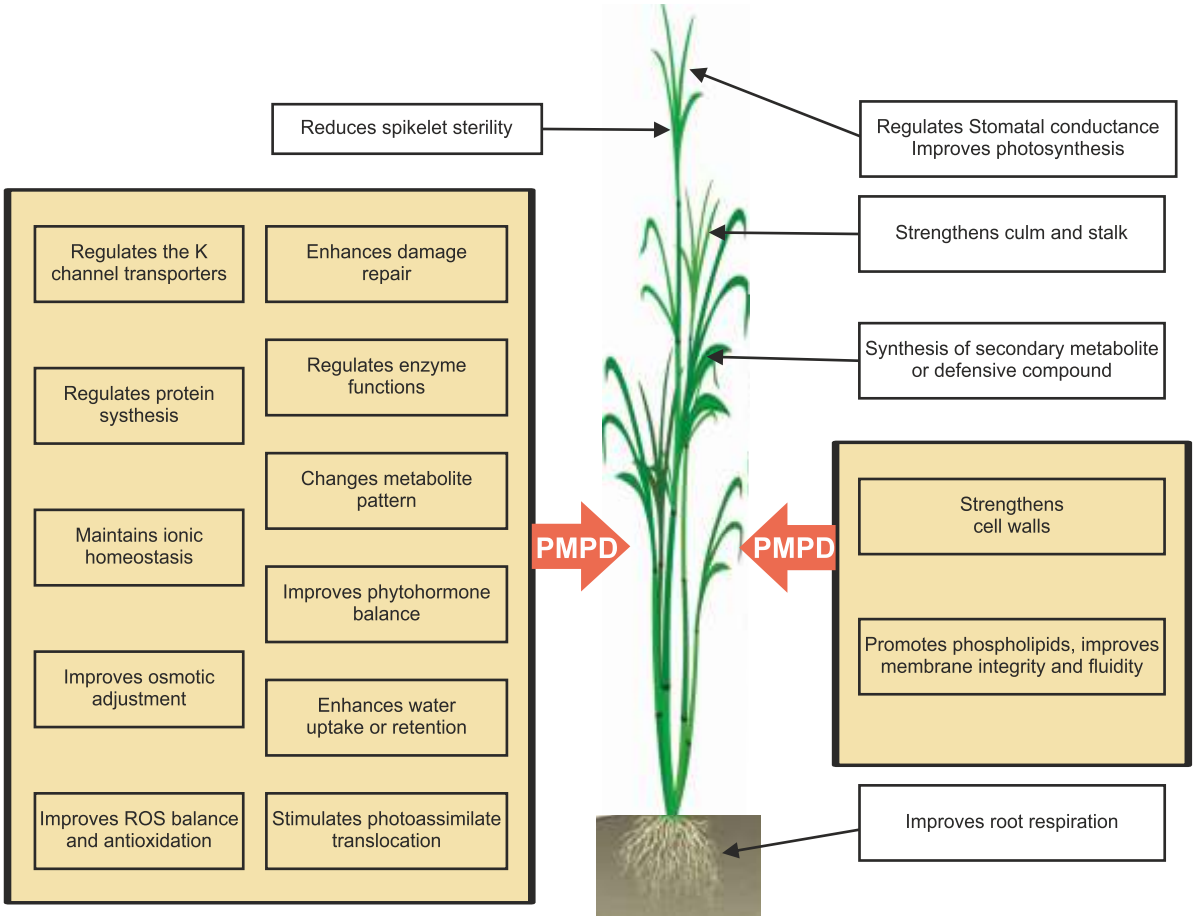
We are working in research on the molecular and biochemical modifications level that are involved in adaptation responses to drought, salt, extreme temperature and excess nutrients and metals in PMPD-treated sugarcane plants.

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

The Role of PMPD-Potash in Crop

- 'K' activates at least sixty enzymes involved in plant growth. Enzymes serve as catalysts for biochemical reactions, being used but not consumed in the process. They bring together other molecules to ensure that the required chemical reaction can take place. Potash from PMPD promotes enzyme activity more efficiently than conventional K+ ion.
- PMPD potash changes the physical shape of the enzyme molecule, exposing the appropriate chemically active sites for reaction in stress. Synergetic potash from PMPD has a major role in alleviating stress since dimer base phosphorus is attached to this potash.
- PMPD potash helps to stabilize the pH between 6 and 7 which is optimum for most enzyme reactions e.g. optimum pH of plasma membrane F1 - AT Pase is 6.0
- Potash is required at every major step in protein synthesis. The reading of genetic code in plant cells to produce proteins and enzymes that regulate all growth processes is possible with adequate 'K'. PMPD potash adds value to 'N' assimilation in crops.



The Role of PMPD-Potash in Crop

With shortage of K, many metabolic processes are affected; including photosynthesis, translocation and enzyme production, at the same time, the rate of dark respiration is increased. The result is reduction in plant growth and quality. Effectiveness of K depends on its nature, i.e. whether it exists as a free ion in solution or as an electro-statically bound cation. Potash is bound with active (dimer) phosphorus in PMPD, a synergetic combination. Hence the profound effects of PMPD are evident in various metabolic processes such as,

1. Chlorophyll development and photosynthesis.

2. Starch formation : starch synthesis is triggered by K from PMPD more effectively than conventional application of potash. Starch builds cellulose and reduces lodging.

3. Sugar transport system uses energy in the form of ATP / NADPH. If K is inadequate, less ATP is available and the transport system breaks down, causing photosynthates to build up in leaves and the rate of photosynthesis is reduced. Translocation of sugars and starch is ensured with regular application of PMPD synergetic potash combination in plants.

4. The activation of enzymes by K and its involvement in adenosine triphosphate (ATP) production is important in regulating the rate of photosynthesis.

   Solar Energy + CO_2 + H_2O = Sugar + O_2 + ATP -The electrical charge balance at the site of ATP production is maintained with synergetic potash ion from PMPD (initial high energy product).

5. Rate of a reaction is controlled by the rate at which PMPD-potash enters a given reaction.

6. Application of such potash effectively controls stomata opening and closure reducing water loss and wilting.

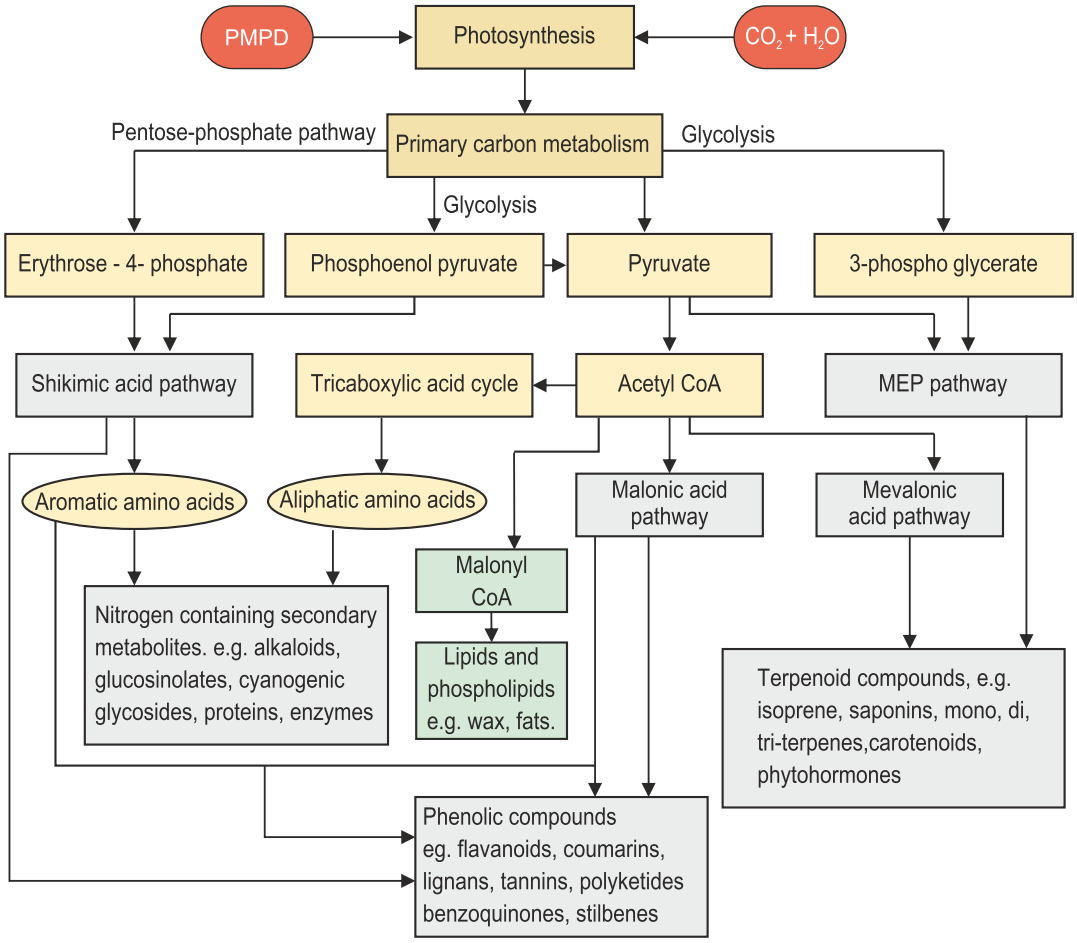
7. PMPD-potash prevents premature cell death more effectively than conventional potash.

8. Uptake of water and nutrients by osmosis by accumulation of K in plant roots produces a gradient of osmotic pressure that draws water into the roots. When K supply is reduced, translocation of nitrates, phosphates, calcium, magnesium and amino acids is depressed. PMPD-potash regulates metabolism.

PMPD Improves Bioefficacy of Applied Fertilizers

Induces Resistance and Builds Tolerance by Activating Stress Metabolism

Impact of PMPD on Plant Metabolic Profile



(Light Yellow : Primary Metabolites and Gray : Secondary Metabolites)

Primary metabolites such as amino acids, proteins, nucleotides, carbohydrates and lipids have a direct role in the plant metabolic processes of respiration, photosynthesis and use of nutrients through assimilation, transport and translocation. These primary metabolites are involved in plant growth, vigour and maturity.

A plant also produces secondary metabolites, which include of toxic chemicals and pathogen-degrading enzymes and can kill plant cell. Production of secondary metabolites is very expensive as it makes great demands on energy and nutrients. Many times, under stressful conditions, growth is compromised to ensure survival.

Impact of PMPD on a Plant in Terms of Metabolites Produced

Bio-active phosphorus greatly influences photosynthesis and carbon metabolism. Under phosphate deficiency, the accumulation of carbohydrates in roots increases significantly, registering positive correlations among the concentration of phosphate in the environment, the concentrate of bioactive phosphorus in the plant and the concentration of hexose phosphate, starch precursor molecule in chloroplasts and of sugar in cytosol, in leaves.

With the addition of 5.0% of total P, in the form of active phosphorus, a significant increment in the concentration of total sugars during the blooming stage was observed. It is a positive effect, because a high concentration of total sugars in the plant leads to early production and increases yield. On the other hand, bio-active phosphorus is a nutrient that has influence on the stability of the chlorophyll molecule. Leaves treated with high concentrations of bioactive P and K turn dark green, indicating a change in the concentration of chlorophyll.

The role of active phosphorus and potash from PMPD in various metabolic processes of plants is complex and not yet fully understood. The responses of PMPD-treated plants are co related to various strategical mechanisms to authenticate its role further. Although there is no consensus so far on its physiological function as a P source for plant nutrition, experimental evidence has shown that bioactive phosphorus can alleviate abiotic and biotic form of stress.

Active phosphorus and potash from PMPD play an important role in increasing plant resistance to abiotic stress. Potash from PMPD has a major role in the survival of crop plants under abiotic stress conditions. Active potash from PMPD has many essential roles in such physiological processes, as photosynthesis, translocation of photosynthates into sink organs, maintenance of turgidity and activation of enzymes under stress conditions.

Low-temperature stress affects the fluidity of membrane lipids, which may alter membrane structure. Low temperature also affects photosynthetic electron transport, stomatal conductance, rubisco activity, and CO_2 fixation in plants due to conversion of 0_2 to ROS.

PMPD-treated plants can modulate a wide range of adaptive or resistance mechanisms to maintain productivity and ensure survival under a variety of environmental forms of stress such as drought, chilling, frost, high temperatures, soil salinity or sodicity and nutrients imbalance.

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Article

Predication of Photosynthetic Leaf Gas Exchange of Sugarcane (*Saccharum* spp) Leaves in Response to Leaf Positions to Foliar Spray of Potassium Salt of Active Phosphorus under Limited Water Irrigation

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ABSTRACT: Sufficient water and fertilizer inputs in agriculture play a major role in crop growth, production, and quality. In this study, the response of sugarcane to limited water irrigation and foliar application of potassium salt of active phosphorus (PSAP) for photosynthetic responses were examined, and PSAP's role in limited water irrigation management was assessed. Sugarcane plants were subjected to limited irrigation (95−90 and 45−40% FC) after three months of germination, followed by a foliar spray (0, 2, 4, 6, and 10 M) of PSAP. The obtained results indicated that limited water irrigation negatively affected sugarcane growth and reduced leaf gas exchange activities. However, the application of PSAP increased the photosynthetic activities by protecting the photosynthetic machinery during unfavorable conditions. Mathematical modeling, a Skewed model, was developed and compared with the existing Gaussian model to describe the photosynthetic responses of sugarcane leaves under the limited irrigation with and without PSAP application. The models fitted well with the observed values, and the predicted photosynthetic parameters were in close relationship with the obtained results. The Skewed model was found to be better than the Gaussian model in describing the photosynthetic parameters of plant leaves positioned over a stem of limited water irrigation and applied PSAP application and is recommended for further application.

1. INTRODUCTION

Sugarcane (*Saccharum* spp.) is one of the major cash crops in the globe, mainly cultivated in dry and semidry regions.[1] China is the third largest cane producer worldwide,[2,3] and the Guangxi province is the leading sugarcane producer, which produces 6−9 million tons of cane sugar, amounting to over 60% of the total production of sugarcane in the country,[3] mainly for sugar and ethanol production. Cane production has rapidly enhanced and gained attention as a feedstock for 2-G ethanol, considered as a source of cleaner energy as relative to fossil fuels.[4]

Limited water is one of the main limiting factors for agricultural crop production. The loss of yield by limited irrigation of crops exceeds about 60% for a variety of plants/crops.[4−6] Limited water which inhibits plant leaf gas exchange and growth traits[1,7,8] is responsible for the loss in crop production.[9,10] However, the impacts of limited water supply vary according to the growth phases.

Photosynthetic capacity is the main physiological process for crop growth and productivity.[11,12] Other related studies have reported that the leaf photosynthetic performance in C_4 crops is very sensitive to fluctuations in soil moisture capacity.[13−18] The inhibitory impacts of insufficient water supply on photosynthetic performance can be linked with low CO_2 levels in the stroma of chloroplasts caused by diffusion limitations through the stomata and the mesophyll,[19] the variation of enzymatic carbon assimilation, and phloem transport limitations.[17,20,21] The closure of stomatal openings is an initial effect to limited irrigation and an efficient way to decrease the loss of water when stress is not too severe; however, it limits carbon dioxide diffusion in the plant leaves for photosynthetic capacity.[18,22,23] The requirement of water under field conditions has been a serious issue since most agricultural areas suffer from seasonal water stress conditions.[4,10,24]

Potassium (K) plays an important role in plant development.[25] The research evidence indicated that the plants subjected to limited irrigation have a more internal requirement for K element,[26,27] and crop productivity-limiting effects of

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Table 1. Influence of PSAP on Leaf Area Expansion (cm^2) in Sugarcane Plants Subjected to Limited Water Irrigation[a]

		leaf position vs leaf area expansion (cm^2)					
irrigation level (% FC)	PSAP (M)	1	2	3	4	5	6
95−90%	0	235.25	251.66	268.32	316.33	317.31	317.39
	2	246.89	263.19	279.19	319.09	320.13	320.98
	4	251.05	273.98	293.01	321.12	323.79	325.02
	6	270.21	298.36	317.61	324.08	325.18	326.61
	10	278.74	302.13	327.31	339.91	342.67	346.09
45−40%	0	172.52	187.8	201.38	206.41	211.02	213.15
	2	184.02	208.18	221.13	227.43	229.19	231.09
	4	185.69	217.09	232.27	239.49	241.01	244.06
	6	199.11	224.16	239.8	251.21	257.94	259.07
	10	209.05	237.96	257.11	264.13	268.09	269.17

[a]Each set of data represents mean of at least five biological replicates. FC = field capacity.

Table 2. Model Constants for the Skewed and Gaussian Models of Control (A) and Limited Irrigation (B) with Foliar Application of PSAP in Sugarcane Plants[a]

		(A) control (95−90% of FC)					
		Skewed model			Gaussian model		
photosynthetic responses	PSAP (M)	α	β	γ	a	b	c
P_N	0	21.60	83.27	17.58	21.97	1.71	3.99
	2	21.97	1634.09	15.78	22.33	1.91	4.14
	4	24.14	104.69	11.92	24.22	1.46	5.05
	6	28.80	14.24	47.96	29.32	0.73	5.67
	10	28.89	34.65	92.81	29.49	0.017	6.27
gs	0	146.38	107.68	5.98	158.13	−1.79	6.43
	2	205.52	156.24	2.71	306.89	−4.09	17.33
	4	259.95	151.97	2.33	199.51	−95.63	25.83
	6	245.28	603.60	2.88	100.48	−109.31	26.79
	10	295.67	722.28	2.12	233.27	−35.47	2.07
E	0	1.98	1.48	18.94	2.03	0.47	4.60
	2	2.04	2.46	14.33	2.07	0.95	4.02
	4	2.27	47.36	8.54	2.27	0.69	4.59
	6	2.90	2.84	10.32	3.04	−0.14	4.55
	10	2.86	7.19	5.74	3.06	−0.89	5.06
		(B) drought (45−40% of FC)					
		Skewed model			Gaussian model		
photosynthetic responses	PSAP (M)	α	β	γ	a	b	c
P_N	0	13.38	5.38	258.18	14.81	−1.41	6.69
	2	15.77	8.39	42.42	17.13	−0.86	5.84
	4	17.57	17.18	7.81	19.18	−1.32	5.96
	6	20.08	22.94	7.37	21.66	−1.05	5.67
	10	20.32	62.38	5.39	22.78	−2.17	6.35
gs	0	91.27	60.04	43.07	92.95	7.28	4.16
	2	97.25	64.25	59.28	98.23	1.26	3.99
	4	123.37	194.81	9.14	124.71	0.63	4.03
	6	128.98	142.99	17.43	130.95	0.99	4.09
	10	129.27	273.39	8.52	130.61	0.62	4.32
E	0	1.13	0.83	5.76	1.39	−6.78	12.41
	2	1.21	2.58	6.07	1.301	−2.84	10.14
	4	1.22	0.81	41.47	1.24	1.69	5.24
	6	1.45	10.42	7.30	1.49	−0.34	6.45
	10	1.28	30.83	11.15	1.30	0.75	6.30

[a]P_N = photosynthesis, gs = stomatal conductance to water vapor, and E = transpiration rate.

limited water supply could be overcome by enhancing K supplementation.[28−30] Under limited water supply, more K is required for the balance of photosynthetic CO_2 assimilation rates, defense of chloroplasts from oxidative damage, impair-

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Table 3. Calculated Values of the Photosynthetic Parameters, That Is, Net Photosynthetic Rate (P_N), Stomatal Conductance to Water Vapor (gs), and Transpiration Rate (E) by the Skewed and Gaussian Models for Different Leaf Positions under Normal Growth Conditions with Foliar Application of PSAP in Sugarcane Plants

	Skewed model					Gaussian model				
	PSAP (M)					PSAP (M)				
leaf position	0	2	4	6	10	0	2	4	6	10
	P_N (μmol CO_2 m^{-2} s^{-1})									
1	21.601	21.975	24.141	28.803	28.802	21.623	21.795	24.121	29.287	29.166
2	21.567	21.920	23.996	28.796	28.415	21.908	22.320	24.078	28.592	28.125
3	20.955	21.440	23.141	27.753	26.616	20.847	21.563	23.110	27.058	26.440
4	19.009	20.006	21.378	24.582	24.081	18.632	19.654	21.328	24.822	24.232
5	15.845	17.308	18.940	21.536	21.455	15.641	16.899	18.925	22.074	21.650
6	11.981	13.282	16.112	19.397	19.018	12.331	13.709	16.147	19.029	18.858
	gs (mmol H_2O m^{-2} s^{-1})									
1	143.66	168.671	187.230	211.566	209.307	143.85	165.301	182.529	209.025	206.113
2	133.35	141.335	154.428	177.398	169.841	132.82	143.547	157.801	179.119	173.372
3	119.65	121.407	132.394	151.068	143.751	119.71	124.242	136.220	153.278	145.650
4	104.97	105.716	115.650	129.946	124.170	105.32	107.176	117.413	130.982	123.301
5	90.294	92.773	102.103	112.401	108.487	90.453	92.146	101.052	111.774	106.611
6	76.011	81.762	90.712	97.445	95.410	75.824	78.962	86.840	95.249	95.793
	E (mmol H_2O m^{-2} s^{-1})									
1	1.985	2.042	2.265	2.903	2.839	2.013	2.067	2.267	2.945	2.851
2	1.968	2.020	2.179	2.803	2.621	1.918	1.998	2.182	2.720	2.597
3	1.763	1.838	2.001	2.401	2.272	1.743	1.816	2.002	2.394	2.275
4	1.461	1.532	1.756	1.943	1.899	1.511	1.551	1.752	2.007	1.916
5	1.211	1.226	1.470	1.567	1.546	1.249	1.246	1.462	1.604	1.552
6	1.033	0.964	1.158	1.281	1.224	0.985	0.941	1.164	1.221	1.209

Table 4. Calculated Values of the Photosynthetic Parameters, That Is, Net Photosynthetic Rate (P_N), Stomatal Conductance to Water Vapor (gs), and Transpiration Rate (E) by the Skewed and Gaussian Models for Different Leaf Positions during Limited Water Irrigation with Foliar Application of PSAP in Sugarcane Plants

	Skewed model					Gaussian model				
	PSAP (M)					PSAP (M)				
leaf position	0	2	4	6	10	0	2	4	6	10
	P_N (μmol CO_2 m^{-2} s^{-1})									
1	13.382	15.775	17.564	20.069	20.040	13.883	16.283	17.776	20.293	20.110
2	13.382	15.740	16.808	19.140	18.493	13.010	15.193	16.418	18.748	18.360
3	12.569	14.179	14.783	16.837	16.348	11.922	13.767	14.743	16.791	16.351
4	10.187	11.650	12.606	14.321	14.123	10.685	12.113	12.871	14.579	14.206
5	8.940	9.963	10.747	12.097	11.998	9.364	10.351	10.925	12.271	12.041
6	8.437	9.001	9.249	10.245	10.025	8.026	8.588	9.016	10.012	9.955
	gs (mmol H_2O m^{-2} s^{-1})									
1	91.275	97.256	123.354	128.989	129.225	92.749	98.018	124.207	130.959	130.112
2	91.117	97.234	119.442	128.222	125.263	88.697	96.556	117.753	127.067	124.123
3	81.961	91.825	105.198	118.202	112.618	80.054	89.327	104.959	116.142	112.239
4	64.798	75.326	86.551	99.170	95.464	68.191	77.611	87.959	100.000	96.203
5	52.320	60.691	68.478	79.633	77.651	54.820	63.329	69.306	81.109	78.160
6	44.836	51.186	52.596	63.104	60.878	41.594	48.530	51.342	61.972	60.192
	E (mmol H_2O m^{-2} s^{-1})									
1	1.135	1.207	1.225	1.452	1.287	1.140	1.210	1.225	1.456	1.301
2	1.092	1.166	1.225	1.399	1.274	1.080	1.160	1.233	1.393	1.276
3	1.018	1.103	1.208	1.303	1.231	1.017	1.101	1.198	1.301	1.221
4	0.944	1.032	1.124	1.183	1.152	0.952	1.035	1.121	1.186	1.139
5	0.879	0.961	1.001	1.053	1.042	0.884	0.964	1.012	1.056	1.036
6	0.824	0.892	0.885	0.975	0.908	0.817	0.889	0.880	0.917	0.919

ment of related disruption in carbohydrate metabolism, regulation of stomatal openings, and relations of water status.[31]

Phosphorus (P) is an essential element for optimum plant growth and development, but its slow mobility in soil results in poor uptake by plant roots, which consequently hinders the growth and metabolism activities.[32,33] Previous studies indicated that P contributes to the enlargement of root morphology, and P deficiency will exacerbate limited water irrigation.[34,35] The

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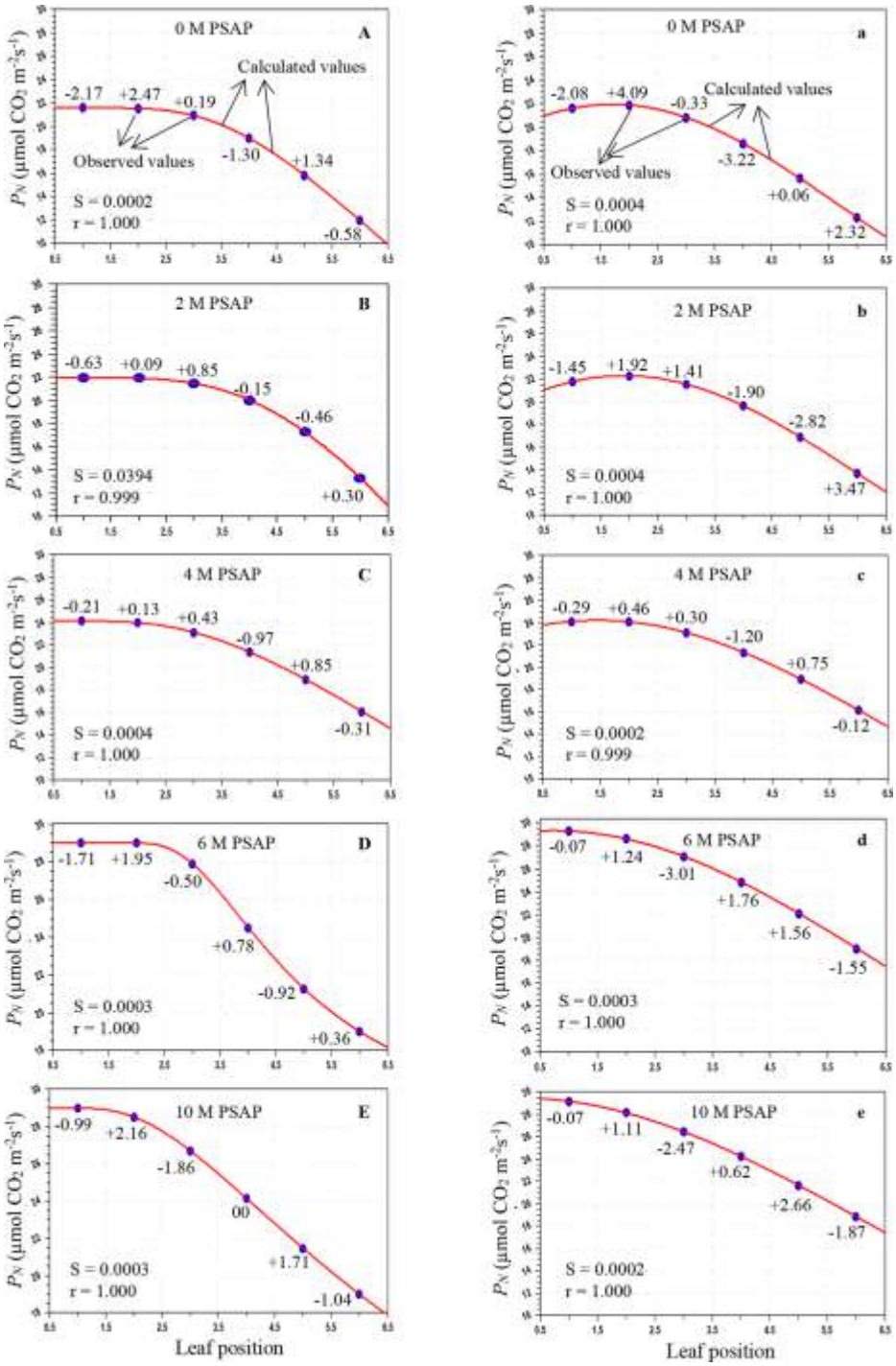

Figure 1. Variation of photosynthesis (P_N; μmol CO_2 m^{-2} s^{-1}) in sugarcane leaves after the application of PSAP (0, 2, 4, 6, and 10 M) under normal irrigation in the Skewed and Gaussian models. Data are represented as the arithmetic mean (n = 3). Blue ovals denote the observed values and red lines show the calculated values. Parenthesis values indicate percent deviation. (A−E) Skewed model, (a−e) Gaussian model, S = standard error, and r = correlation coefficient.

application of P decreases its deficiency in soil, enhances the stress-tolerance mechanism of plants,[36] and results in adaptations of morpho-physiological and biochemical activities that upregulate plant performance.[33,37−41]

However, knowledge about how potassium salt of active phosphorus (PSAP) regulates the photosynthetic variation in sugarcane plants subjected to limited water irrigation remains elusive. In addition, available information concerning the specific dose of PSAP for its application method in sugarcane crops is very limited and thus warrants an in-depth assessment. Exposure to severe water stress may affect the photosynthetic capacity of sugarcane plants with the effects on the leaves varying with leaf position (+1−6th, top to bottom). The plant performance/productivity is actually associated with the accumulated photosynthetic activities and hence with the cumulative photosynthesis, so the response of sugarcane plants to limited irrigation in relation to plant leaf position should be better understood. This study was devoted to develop a

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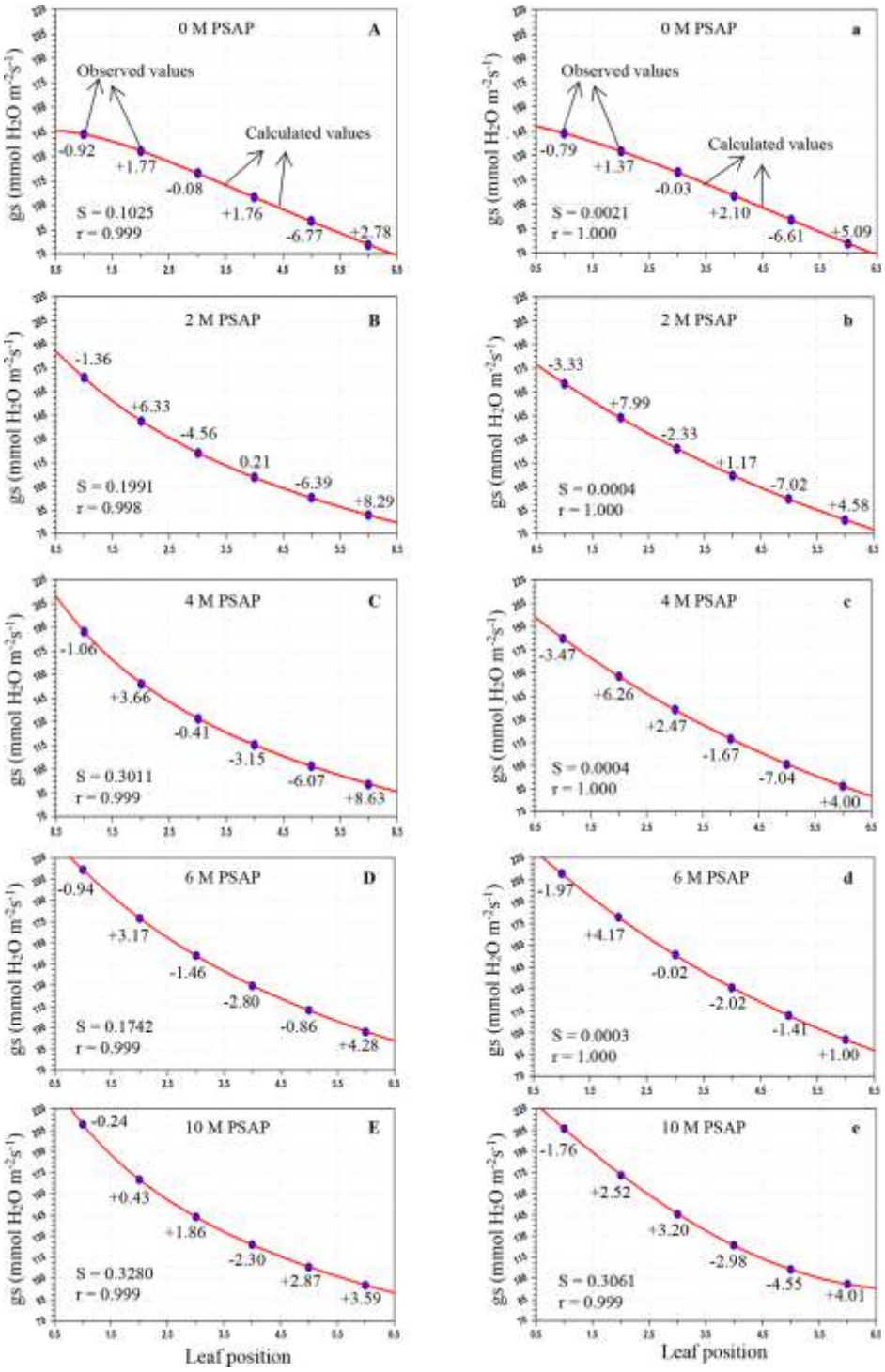

Figure 2. Variation of stomatal conductance to water vapor (gs; mmol H_2O m^{-2} s^{-1}) in sugarcane leaves after application of PSAP (0, 2, 4, 6, and 10 M) under normal irrigation in the Skewed and Gaussian models. Data are represented as the arithmetic mean (n = 3). Blue ovals denote the observed values and red lines show the calculated values. Parenthesis values indicate percent deviation. (A–E) Skewed model, (a–e) Gaussian model, S = standard error, and r = correlation coefficient.

mathematical modeling for correlating the photosynthetic activities against leaf position over the main stem that could be helpful in integrating the photosynthetic parameters in each leaf of the main stem.

2. RESULTS

Sugarcane plants (*Saccharum* hybrid cv. GT 42) were used to examine the photosynthetic traits to limited irrigation and impact of PSAP by foliar application. The observed position-wise (from top to bottom since leaf + 1) leaf area expansion is given in Table 1. The model constants (regression coefficient) for the Skewed model, that is, α, β, and γ, and for the Gaussian model, that is, a, b, and c, of the control and limited irrigation (95–90 and 45–40% of FC) with PSAP (0, 2, 4, 6, and 10 M) in sugarcane plants are shown in Table 2. The calculated values of the photosynthetic parameters such as the net photosynthetic

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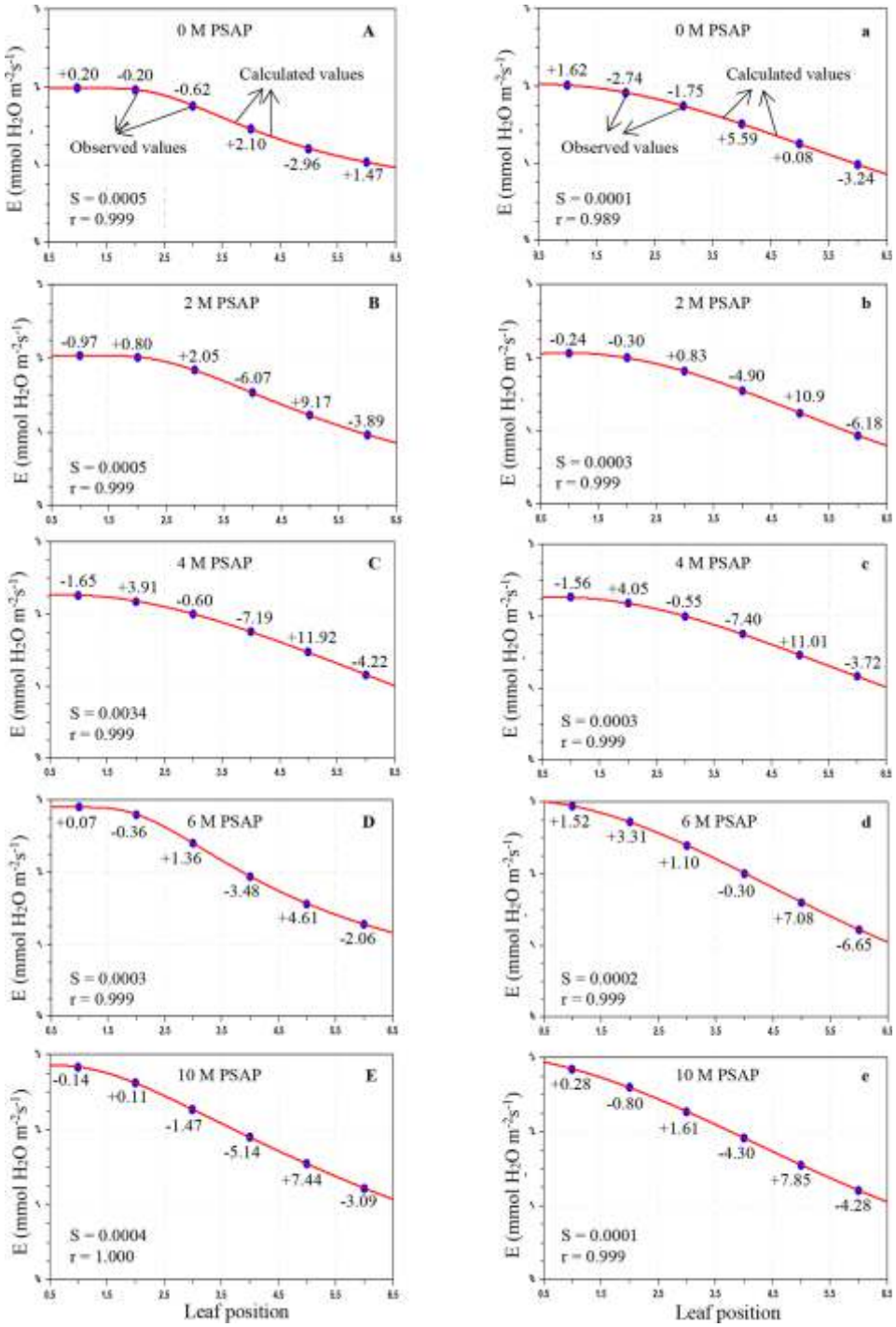

Figure 3. Variation of the transpiration rate (E; mmol H_2O m^{-2} s^{-1}) in sugarcane leaves after application of PSAP (0, 2, 4, 6, and 10 M) under normal irrigation in the Skewed and Gaussian models. Data are represented as the arithmetic mean ($n = 3$). Blue ovals denote the observed values and red lines show the calculated values. Parenthesis values indicate percent deviation. (A–E) Skewed model, (a–e) Gaussian model, S = standard error, and r = correlation coefficient.

rate (P_N), stomatal conductance to water vapor (gs), and transpiration rate (E) with the Skewed and Gaussian models of normal and treated plants with PSAP application are represented in Tables 3 and 4 and Figures 1–6.

As shown in Table 3, under normal irrigation with different concentrations of PSAP, the calculated values of the P_N for the Skewed model were in the range of 28.803–11.981 μmol CO_2 m^{-2} s^{-1}, and for the Gaussian model, the range was 29.287–12.331 μmol CO_2 m^{-2} s^{-1}; the predicted gs for the Skewed model ranges from 211.566 to 76.011 mmol H_2O m^{-2} s^{-1} and that for the Gaussian model ranges from 209.025 to 75.824 mmol H_2O m^{-2} s^{-1}; and the E for the Skewed model ranges from 2.903 to 0.964 mmol H_2O m^{-2} s^{-1} and that for the Gaussian model ranges from 2.945 to 0.941 mmol H_2O m^{-2} s^{-1}. For drought stress (45–40% of FC) with foliar application of PSAP, the calculated values of P_N for the Skewed model range from 20.069 to 8.437 μmol CO_2 m^{-2} s^{-1} and those for the Gaussian model range from 20.293 to 8.026 μmol CO_2 m^{-2} s^{-1}; the

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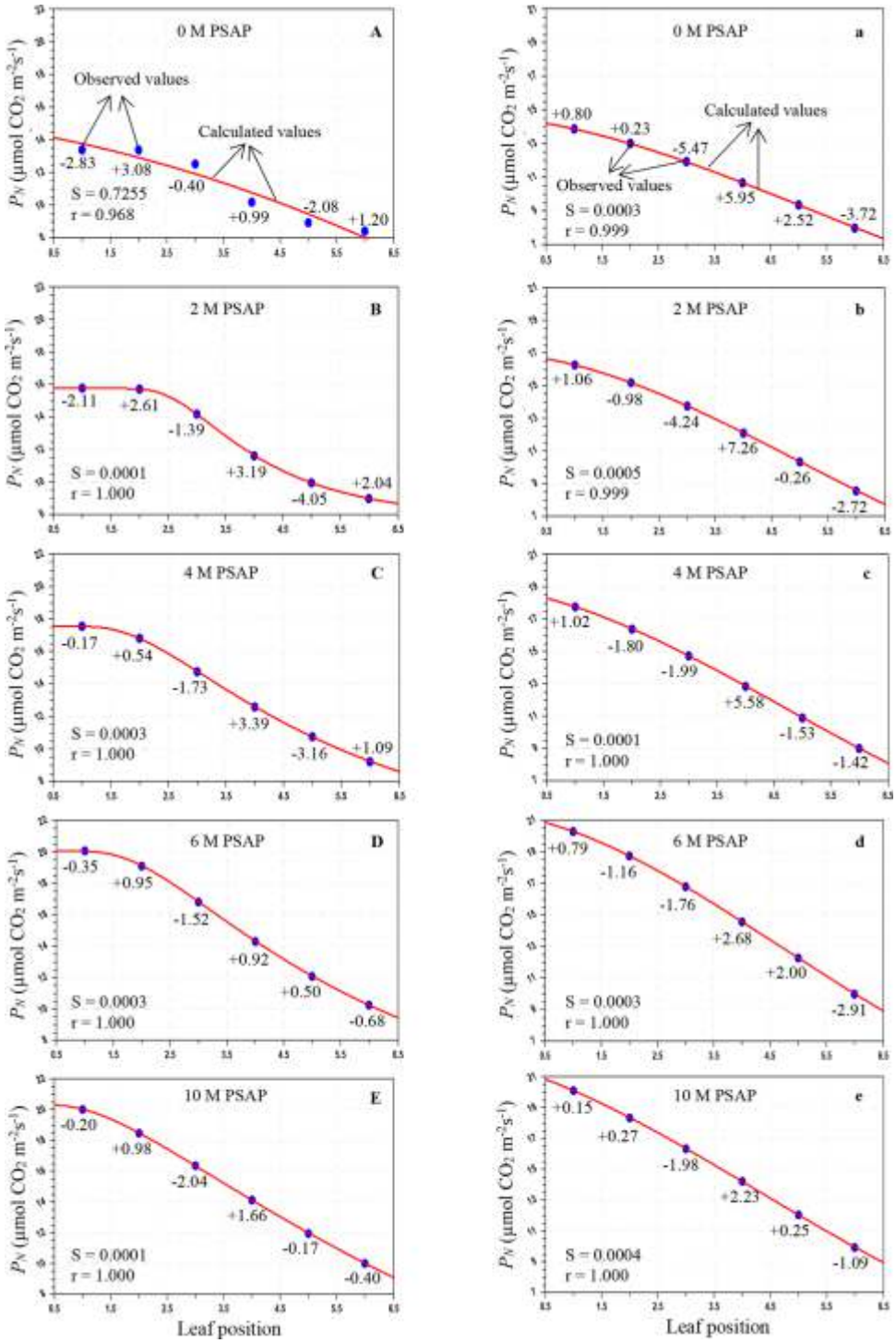

Figure 4. Variation of photosynthesis (P_N; μmol CO_2 m^{-2} s^{-1}) in sugarcane leaves after application of PSAP (0, 2, 4, 6, and 10 M) under limited water irrigation in the Skewed and Gaussian models. Data are represented as the arithmetic mean ($n = 3$). Blue ovals denote the observed values and red lines show the calculated values. Parenthesis values indicate percent deviation. (A–E) Skewed model, (a–e) Gaussian model, S = standard error, and r = correlation coefficient.

predicted gs for the Skewed model ranges from 128.989 to 44.836 mmol H_2O m^{-2} s^{-1} and that for the Gaussian model ranges from 130.959 to 41.594 mmol H_2O m^{-2} s^{-1}; and the E for the Skewed model ranges from 1.452 to 0.824 mmol H_2O m^{-2} s^{-1} and that for the Gaussian model ranges from 1.456 to 0.817 mmol H_2O m^{-2} s^{-1}.

The average percent (%) deviation was maximum for the predicted values of the net photosynthetic rate, stomatal conductance to water vapor, and transpiration rate by the Skewed and Gaussian models in the control and stressed plants with PSAP application (Tables 5 and 6). As may be seen from Table 5, for normal irrigation with PSAP application, the present deviations of the predicted P_N for the Skewed model range from +2.47 to −2.17% and those for the Gaussian model range from +4.09 to −3.22%, and the stomatal conductance and transpiration rate for the Skewed model range from +8.63 to

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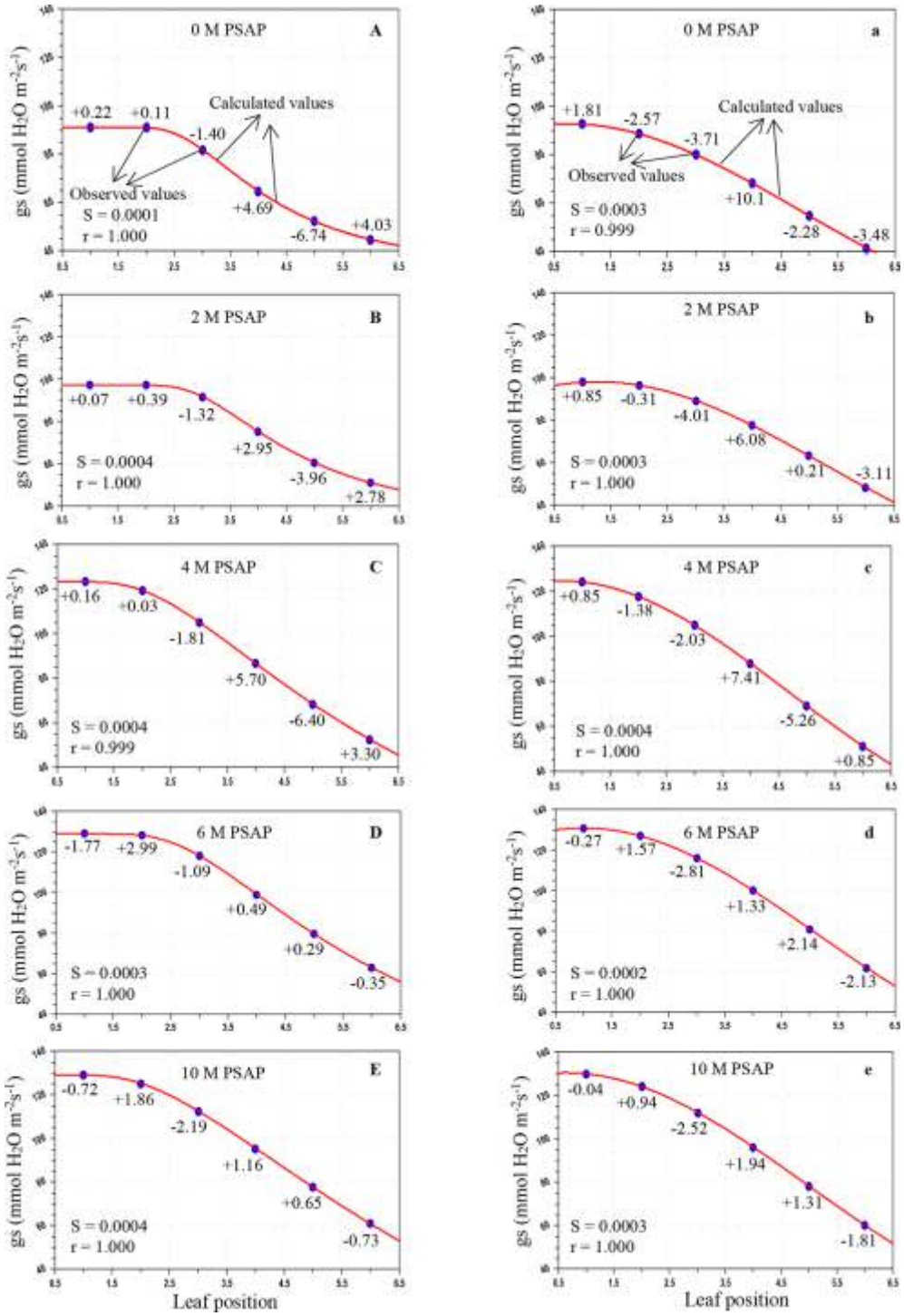

Figure 5. Variation of stomatal conductance to water vapor (gs; mmol H_2O m^{-2} s^{-1}) in sugarcane leaves after application of PSAP (0, 2, 4, 6, and 10 M) under limited water irrigation in the Skewed and Gaussian models. Data are represented as the arithmetic mean ($n = 3$). Blue ovals denote the observed values and red lines show the calculated values. Parenthesis values indicate percent deviation. (A–E) Skewed model, (a–e) Gaussian model, S = standard error, and r = correlation coefficient.

−6.77 and +11.62 to −7.19%, respectively, and those for the Gaussian model range from +7.99 to −7.04 and +11.01 to −7.40%, respectively. When PSAP was supplied as foliar application with limited water irrigation of sugarcane plants, the deviations of the predicted photosynthetic capacity were enhanced for both models. With the Skewed model, the % deviations of the ranges of the calculated P_N, gs, and E were +3.36 to −4.05, +5.70 to −6.74, and +7.50 to −3.52%, respectively. Similarly, with the Gaussian model, the ranges of the percent deviations of the predicted values of P_N, gs, and E were +7.26 to −5.47, +10.18 to −5.26, and +3.91 to −4.61%, respectively.

Overall mean percent deviations of the Skewed and Gaussian models were 0.913, 2.978, and 2.968% and 1.539, 3.231, and 3.526%, respectively, for P_N, gs, and E of PSAP application under control conditions, and 1.546, 1.995, and 1.536% and 2.195,

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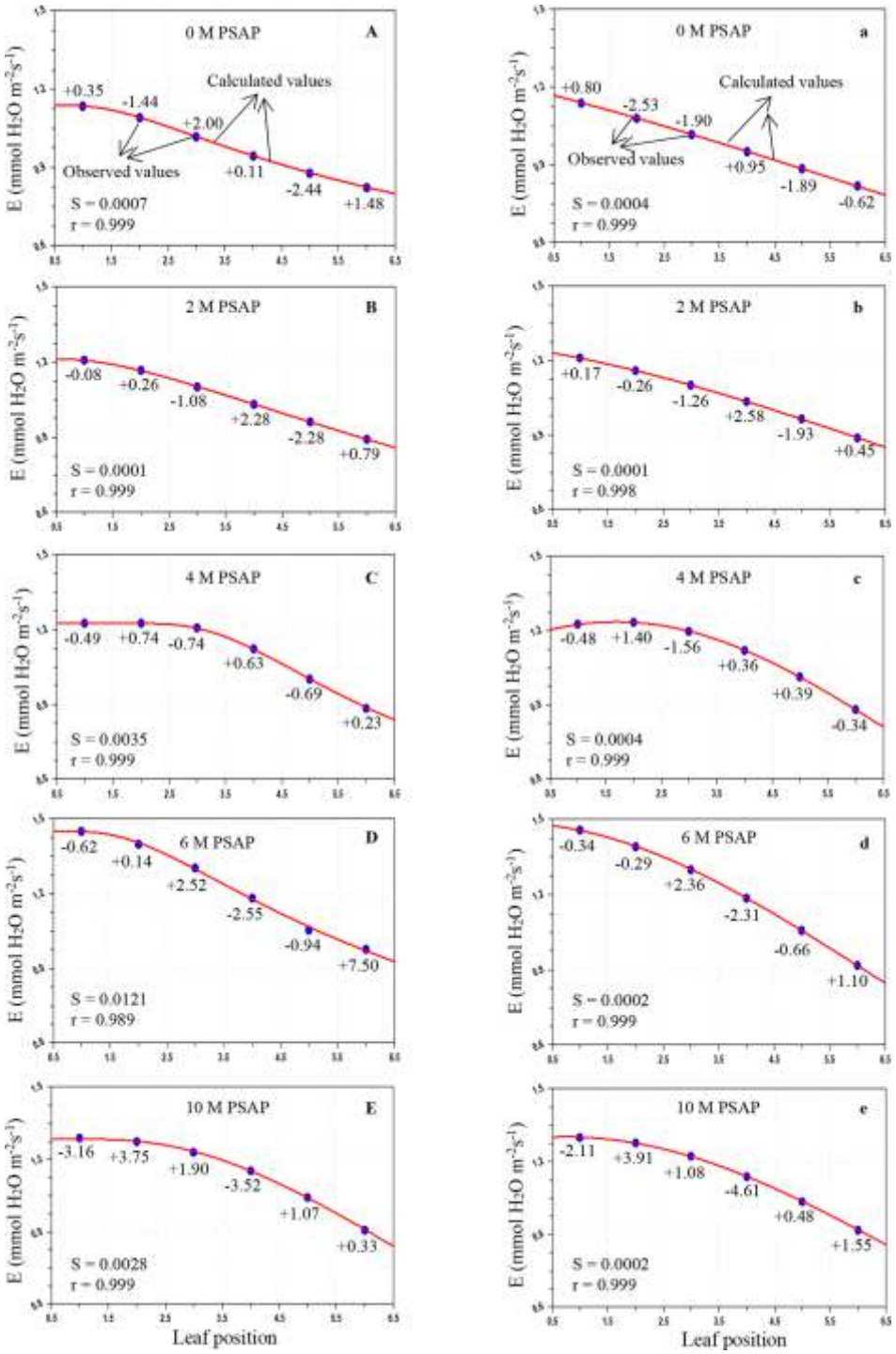

Figure 6. Variation of transpiration rate (E; mmol H_2O m^{-2} s^{-1}) in sugarcane leaves after application of PSAP (0, 2, 4, 6, and 10 M) under limited water irrigation in the Skewed and Gaussian models. Data are represented as the arithmetic mean ($n = 3$). Blue ovals denote the observed values and red lines show the calculated values. Parenthesis values indicate percent deviation. (A−E) Skewed model, (a−e) Gaussian model, S = standard error, and r = correlation coefficient.

2.506, and 1.356%, respectively, under limited water with PSAP. The Skewed model should be used for future studies for modeling the photosynthetic responses of sugarcane against leaf positions.

Under control conditions with foliar application of PSAP, the correlation coefficients (r) for P_N, gs, and E in the Skewed model were found to be 0.999−1.000, 0.998−0.0999, and 0.999−1.000, respectively and those in the Gaussian model were found to be 0.999−1.000, 0.999−1.000, and 0.989−0.999, respectively. Under limited water irrigation with PSAP application, the r values for P_N, gs, and E were found to be 0.968−1.000, 0.999−1.000, and 0.989−0.999, respectively, in the Skewed model, and 0.999−1.000, 0.999−1.000, and 0.998−0.999, respectively, in the Gaussian model. The "r" values were higher in the Skewed model than in the Gaussian model for control and stressed plants with different levels of PSAP. The Skewed model is superior to

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Table 5. The Percentage Deviations (±) of the Calculated Values of Photosynthetic Responses by the Skewed and Gaussian Models for Different Leaf Positions under Control Conditions (95−90% FC) with PSAP Application in Sugarcane Plants

	Skewed model						Gaussian model					
	PSAP (M)						PSAP (M)					
leaf position	0	2	4	6	10	average	0	2	4	6	10	average
						P_N (μmol CO_2 m^{-2} s^{-1})						
1	−2.17	−0.63	−0.21	−1.71	−0.99	1.142	−2.08	−1.45	−0.29	−0.07	−0.07	0.792
2	+2.47	+0.09	+0.13	+1.95	+2.16	1.36	+4.09	+1.92	+0.46	+1.24	+1.11	1.764
3	+0.19	+0.85	+0.43	−0.50	−1.84	0.762	−0.33	+1.41	+0.30	−3.01	−2.47	1.504
4	−1.30	−0.15	−0.97	+0.78		0.8	−3.22	−1.90	−1.20	+1.76	+0.62	1.74
5	+1.34	−0.46	+0.85	−0.92	+1.71	1.056	+0.06	−2.82	+0.75	+1.56	+2.66	1.57
6	−0.58	+0.30	−0.31	+0.36	−1.04	0.518	+2.32	+3.47	−0.12	−1.55	−1.87	1.866
average	1.342	0.413	0.483	1.037	1.29	0.913	2.017	2.162	0.52	1.532	1.467	1.539
						gs (mmol H_2O m^{-2} s^{-1})						
1	−0.92	−1.36	−1.06	−0.94	−0.24	0.904	−0.79	−3.33	−3.47	−1.97	−1.76	2.264
2	+1.77	+6.33	+3.99	+3.17	+0.43	3.318	+1.37	+7.99	+6.26	+4.17	+2.52	4.462
3	−0.08	−4.56	−0.41	−1.46	+1.86	1.674	−0.03	−2.33	+2.47	−0.02	+3.20	1.61
4	+1.76	−0.21	−3.15	−2.80	−2.30	2.044	+2.10	+1.17	−1.67	−2.02	−2.98	1.988
5	−6.77	−6.39	−6.07	−0.86	−2.87	4.592	−6.61	−7.02	−7.04	−1.41	−4.55	5.326
6	+2.78	+8.29	+8.63	+4.28	+3.59	5.514	+5.09	+4.58	+4.00	+1.00	+4.01	3.736
average	2.347	4.523	3.885	2.252	1.882	2.978	2.665	4.403	4.152	1.765	3.17	3.231
						E (mmol H_2O m^{-2} s^{-1})						
1	+0.20	−0.97	−1.65	+0.07	−0.14	0.606	+1.62	−0.24	−1.56	+1.52	+0.28	1.044
2	−0.20	+0.80	+3.91	−0.36	+0.11	1.076	−2.74	−0.30	+4.05	+3.31	−0.80	2.24
3	−0.62	+2.05	−0.60	+1.39	+1.47	1.226	−1.75	+0.83	−0.55	+1.10	+1.61	1.168
4	+2.10	−6.07	−7.19	−3.48	−5.14	4.796	+5.59	−4.90	−7.40	−0.30	−4.30	4.498
5	−2.96	+9.17	+11.62	+4.61	+7.44	7.16	+0.08	+10.95	+11.01	+7.08	+7.85	7.394
6	+1.47	−3.89	−4.22	−2.06	−3.09	2.946	−3.24	−6.18	−3.72	−6.65	−4.28	4.814
average	1.258	3.825	4.865	1.995	2.898	2.968	2.503	3.9	4.715	3.327	3.187	3.526

Table 6. Percentage Deviations (±) of the Calculated Values of Photosynthetic Parameters by the Skewed and Gaussian Models for Different Leaf Positions during Limited Irrigation (45−40% FC) with PSAP Application in Sugarcane Plants

	Skewed model						Gaussian model					
	PSAP (M)						PSAP (M)					
leaf position	0	2	4	6	10	average	0	2	4	6	10	average
						P_N (μmol CO_2 m^{-2} s^{-1})						
1	−2.83	−2.11	−0.17	−0.35	−0.20	1.132	+0.80	+1.06	+1.02	+0.79	+0.15	0.764
2	+3.08	+2.61	+0.54	+0.95	+0.98	1.632	+0.23	−0.98	−1.80	−1.16	+0.27	0.888
3	−0.40	−1.39	−1.73	−1.52	−2.04	1.416	−5.47	−4.24	−1.99	−1.76	−1.98	3.088
4	+0.99	+3.19	+3.36	+0.92	+1.66	2.024	+5.95	+7.26	+5.58	+2.68	+2.23	4.74
5	−2.08	−4.05	−3.16	+0.50	−0.17	1.992	+2.52	−0.29	−1.53	+2.00	+0.25	1.318
6	+1.20	+2.04	+1.09	−0.68	−0.40	1.082	−3.72	−2.72	−1.42	−2.91	−1.09	2.372
average	1.763	2.565	1.675	0.82	0.908	1.546	3.115	2.758	2.223	1.883	0.995	2.195
						gs (mmol H_2O m^{-2} s^{-1})						
1	+0.22	+0.07	+0.16	−1.77	−0.72	0.588	+1.81	+0.85	+0.85	−0.27	−0.04	0.764
2	+0.11	+0.39	+0.03	+2.49	+1.86	0.976	−2.57	−0.31	−1.38	+1.57	+0.94	1.354
3	−1.40	−1.32	−1.81	−1.09	−2.19	1.562	−3.71	−4.01	−2.03	−2.81	−2.52	3.016
4	+4.69	+2.95	+5.70	+0.49	+1.16	2.998	+10.18	+6.08	+7.41	+1.33	+1.94	5.388
5	−6.74	−3.96	−6.40	+0.29	+0.65	3.608	−2.28	+0.21	−5.26	+2.14	+1.31	2.24
6	+4.03	+2.78	+3.30	−0.35	−0.73	2.238	−3.48	−3.11	+0.85	−2.13	−1.81	2.276
average	2.865	1.911	2.9	1.08	1.218	1.995	4.005	2.428	2.963	1.708	1.427	2.506
						E (mmol H_2O m^{-2} s^{-1})						
1	+0.35	−0.08	−0.49	−0.62	−3.16	0.94	+0.80	+0.17	−0.48	−0.34	−2.11	0.78
2	−1.44	+0.26	+0.74	+0.14	+3.75	1.266	−2.53	−0.26	+1.40	−0.29	+3.91	1.678
3	+2.00	−1.08	−0.74	+2.52	+1.90	1.648	+1.90	−1.26	−1.56	+2.36	+1.08	1.632
4	+0.11	+2.28	+0.63	−2.55	−3.52	1.818	+0.95	+2.58	+0.36	−2.31	−4.61	2.162
5	−2.44	−2.24	−0.69	−0.94	+1.07	1.476	−1.89	−1.93	+0.39	−0.66	+0.48	1.07
6	+1.48	+0.79	+0.23	+7.50	+0.33	2.066	−0.62	+0.45	−0.34	+1.10	+1.55	0.812
average	1.303	1.122	0.587	2.378	2.288	1.536	1.448	1.108	0.755	1.177	2.29	1.356

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the Gaussian model. The Skewed model predicted more closely, the values of the photosynthetic traits of control and limited irrigation with PSAP application and may hence be recommended for further application.

3. DISCUSSION

Insufficient water irrigation is well-known for its inhibitory effects. It reduces crop growth, development, and ultimately productivity.[42−44] Limited water irrigation decreases photosynthetic responses due to the reduction in leaf area expansion and linked damage to the photosynthetic apparatus.[45] Plants have developed numerous types of adaptive mechanisms to respond to stresses. In this experiment, the protective role of the PSAP fertilizer was assessed in sugarcane plants subjected to limited water irrigation. However, the application of PSAP as foliar spraying decreased the severity of limited irrigation-induced growth inhibition. It increased sugarcane tolerance to limited irrigation in terms of maintaining and/or improving the photosynthetic responses. During limited irrigation, stomatal closure is one of the initial plant responses to reduce the loss of water, accompanied by a remarkable reduction in stomatal conductance to water vapor and consequently, stomatal limitation of photosynthetic CO_2 assimilation rates.[18,43,46,47] The PSAP application also resulted in an enhanced rate of transpiration, possibly driven by the increased gs to improve a steady state of P_N subjected to limited irrigation (Figures 1−6).

Stomatal closure is considered a major factor in reducing the photosynthetic CO_2 assimilation rate subjected to limited irrigation.[18,43,48] Stomatal closure in response to limited soil moisture occurs because roots release higher abscisic acid (ABA) concentration to the xylem, and as a result, the enhanced pH of the xylem sap promotes ABA loading and subsequent uptake to the shoots.[49] The loss of gs limits leaf gas exchange activities and reduces C_i levels and photosynthetic rates due to downregulation of Rubisco activity.[50] The present findings are consistent with previous observations that have demonstrated increased photosynthetic responses in various plant varieties/cultivars treated with P application subjected to stress conditions.[33,41,51,52]

Plant leaves are the most important factors for the photosynthetic activities, and the area of leaves depends on light harvesting, which affects gas exchange activities and the accumulation of photosynthetic products.[12,18,53] The present study noted that on all limited irrigation levels, photosynthetic capacity with PSAP was higher than that without PSAP application (Figures 4−6). The photosynthetic CO_2 assimilation rate reflects leaf gas exchange characteristics of plants and is the important factor to achieve the maximum crop productivity.[6,12,54] Limited water irrigation levels could significantly downregulate sugarcane photosynthesis and productivity.[18,55]

Soil irrigation is a common technique for the application of essential nutrients to plants. However, plants can also absorb mineral nutrients when supplied as a foliar spray in the required dose.[27,56] The foliar application facilitates the continued absorption of mineral elements, and it can be performed throughout the growth period, particularly during the apex phase of nutrient requirement without the interaction with soil particles.[57] There are limited studies on the impact of foliar application of K to correct deficiency signs and upgrade plant performance and production.[58] The status of water in plant leaves depends on stomatal regulation and supply of water from the vasculature to internal plant organs.[27,59]

Modeling of photosynthetic responses of plants is essentially required for assessing overall growth and productivity of agricultural crops. Photosynthetic responses can be integrated in terms of productivity of the leaf area expansion, and temporal variations of photoassimilation are known in response to leaf positions. The Gaussian and Skewed models have been used for explaining variations of physiological responses against leaf positions. The best performing model was the Skewed model, which explained the variations of physiological responses against leaf positions of sugarcane under normal and limited water irrigation with PSAP application. The model may be quite useful for future studies in relating crop responses against any type of nutrient and water treatment.

In conclusion, overall, the present results revealed that the PSAP application might be an efficient technique for improving the tolerance of sugarcane plants subjected to limited water irrigation. It also upregulated the photosynthetic capacity by protecting the negative impacts of sugarcane plants during limited irrigation. Taken together, PSAP has a significant role in sugarcane cultivation under insufficient water availability for irrigation and its optimum dose will be supportive in mitigation of limited irrigation in a variety of crops for sugar and bioenergy sectors. This combination also greatly improved the photosynthetic activities and plant growth. However, to suggest an optimum dose of PSAP concentration, a large-scale demonstration under field conditions should be assessed in later studies.

4. EXPERIMENTAL SECTION

4.1. Plant Material, Experimental Site, and Design. The sugarcane (*Saccharum* spp. cv. GT 42) plants were provided by Sugarcane Research Institute, Guangxi Academy of Agricultural Sciences, Nanning, Guangxi, China (22°49′ N, 108°18′ E, 800−1731 masl), and the experiment was conducted in an open greenhouse during 2020 with three replications of each treatment as a completely randomized block design. The soil of the experiment was silty clay soil. One-bud cane sets were planted in the month of mid-March 2020, following the farmer's standard practices. Row-to-row spacing was maintained (about 75 cm). Recommended basal dose of fertilizers (N/P/K) was applied. Plants were raised with a standard dose of fertilizer for three months and then exposed to limited water irrigation (drought stress) by withholding irrigation, while control plants were watered regularly and manually. Uniform plants were selected and maintained for each treatment (control and limited irrigation), and the solution of PSAP (0, 2, 4, 6, and 10 M) was applied on the upper parts (canopies) of the plant manually using a sprayer. The spraying was done only with distilled water (without PSAP) over control and stressed plants. The water treatment included normal water irrigation (95−90% of field capacity) and limited water irrigation (45−40% of FC). Soil field capacity (moisture level, %) was measured using a soil moisture meter (0−10 cm soil depth) during experiment. The PSAP source was 85% salt of potassium and phosphorus and 15% other nutrients. The PSAP solution was prepared by dissolving the appropriate concentration of PSAP in distilled water. PSAP was applied once at one-month intervals up to three months during limited irrigation. PSAP is non-poisonous and environment friendly. This salt is manufactured by the Isha Agro-Sciences Private Limited, Pune, India.

4.2. Leaf Gas Exchange. Plant leaf gas exchange characteristics such as the net photosynthetic rate (P_N), stomatal conductance to water vapor (gs), and transpiration rate (E)

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were observed on 90 days subjected to limited water irrigation with foliar application of PSAP in sugarcane plants using an Li-6800 portable photosynthesis system (Li-COR Biosciences, Lincoln, NE, US). For each treatment, leaf photosynthetic parameters were recorded between 09:30 and 11:00 h on both treated and non-treated plants (three replicates). In each treatment, position-wise leaves (+1 to +6 from the top to middle part of the leaf) were used for photosynthetic responses without changing the leaf angle. The photosynthetic photon flux density, air temperature, and CO_2 concentration were set at 1200 μmol m^{-2} s^{-1}, 25 °C, and 400 ppm, respectively, inside the leaf chamber. As photosynthetic response rates change linearly along the length of the leaf, observing at the middle of the leaf provides an estimate of the integrated whole photosynthetic rate.

4.3. Models. Verma et al.[60] developed the first model to describe physiological responses of plant leaves over a stem/twig, which followed the normal distribution pattern. Measured values of the CO_2 assimilation (P_N), stomatal conductance to water vapor (g_s), and transpiration rate (E) of sugarcane leaves with respect to their positions fitted best in the model. The Gaussian model given by Verma et al.[61] is written as below.

$$p_n = p_m e^{-1/2\left(\frac{n-b}{c}\right)^2} \quad (1)$$

where b and c = constants, p_n = the physiological response against the leaf position, n, and p_m = the maximum physiological response.

Verma et al.[61] developed the second model by combining the following hypotheses: (a) the rate of change of physiological responses with respect to the leaf position (dp/dn) is directly proportional to the physiological response (p) and (b) the rate of change of physiological responses with respect to the leaf position is directly proportional to the physiological response and inversely proportional to the leaf position. The following governing equation was developed.

$$\frac{dp}{dn} = \lambda p + \mu\frac{p}{n} \quad (2)$$

where, p = physiological response, n = leaf position, and μ and λ are the model constants.

They solved the above equation and obtained the following solution.

$$p_n = e^{C}\cdot e^{\lambda n}\cdot e^{\mu \log_e n}$$

$$p_n = \gamma\cdot e^{n\log_e \omega}\cdot e^{\mu \log_e n} \quad (3)$$

where, $\lambda = \log_e \omega$ and $\gamma = e^C$. The derived model was called as the Skewed model.

Both the models were fitted in the present study for a comparative study to find the best one.

4.4. Model Validations and Comparison with the Existing Model. Measured values of CO_2 assimilation (P_N), stomatal conductance to water vapor (g_s), and transpiration rate (E) of sugarcane leaves with respect to their position were fitted in the derived "Skewed model" for validation. The same data were also fitted in the Gaussian model of Verma et al.[61] for comparison purposes.

4.5. Statistical Analyses. Statistical analyses were performed between or within limited water irrigations, depending on parameters using CurveExpert 1.4 software.

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[▽]K.K.V. and X.P.S. have contributed equally to this work.

Notes

The authors declare no competing financial interest.

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1) **Phosphonate Levels in Avocado (Persea americana) Seedlings and Soil Following Treatment with Fosetyl-Al or Potassium Phosphonate.** D. G. Ouimette, Graduate Research Assistant, Department of Plant Pathology, University of California, Riverside 92521-0122. M. D. Coffey, Professor, Department of Plant Pathology, University of California, Riverside 92521-0122. Plant Dis. 73:212-215. Accepted for publication 5 October 1988. Copyright 1989 The American Phytopathological Society. DOI: 10.1094/PD-73-0212.

The levels of ethyl phosphonate and phosphonate in avocado seedlings and soil were determined using high-performance ion chromatography at 1, 2, 4, 6, and 8 wk following foliar or soil applications of either 3 mg/ml of fosetyl-Al or 2.1 mg/ml of potassium phosphonate. After soil treatment with either potassium phosphonate or fosetyl-Al, phosphonate persisted in soil for 2 and 4 wk, respectively. With fosetyl-Al, low levels of ethyl phosphonate were present in soil, roots, and stems 1 wk after application, but none was detected thereafter. In contrast, no ethyl phosphonate residues were detected in either soil or avocado tissue 1 wk following foliar application of fosetyl-Al. Soil treatment with both potassium phosphonate and fosetyl-Al resulted in much higher phosphonate levels being present in all tissues compared with foliar treatment (up to 78 and 94 times more in the root samples following potassium phosphonate and fosetyl-Al treatment, respectively). Following both soil and foliar applications of the two fungicides, high phosphonate levels were maintained in avocado tissues for the 8-wk period of the experiments, suggesting that phosphonate is stable in plants. The phosphonate levels found in roots after either soil or foliar applications were sufficiently high to account for a direct antifungal effect in controlling avocado root rot caused by Phytophthora cinnamomi.

2) **C.J.Lovatt and R.L.Mikkelsen, 2006. Phosphite Fertilizers: What are they? Can you use them? What can they do? Better crops/Vol 90**

Abstract

Interest is growing in phosphite as part of a total production program. Phosphite contains one less oxygen (O) than phosphate, making its chemistry and behavior quite different. Phosphite is more soluble than phosphate, making leaf and root uptake more efficient, thus high concentrations can be toxic for plants. Phosphite also has unique effects on plant metabolism.

Phosphite supplied through the soil or foliage is slowly converted to phosphate. Soil and foliar applications are made at relatively low rates to prevent nutrition

problems. For some plant species, phosphite may offer some unique benefits not seen with phosphate applications.

3) **Hoang Thi Bich Thao and Takeo Yamakawa : Phosphite (Phosphorus acid): Fungicide, Fertilizer or Bio-Stimulator? Soil Science Plant Nutrition 55(5):228-234 Kyushu University, Japan.**

Abstract

Phosphite (Phi), a reduced form of phosphate (Pi), is widely marketed as either a fungicide or fertilizer or sometimes as a bio-stimulant. This is confusing for both distributors and growers. The present paper explores data from various studies to clarify that Phi does not provide plant P nutrition and thus cannot complement or substitute Pi at any rate. In addition, Phi itself does not have any beneficial effect on the growth of healthy plants, regardless of whether it is applied alone or in combination with Pi at different ratios or different rates. Plants fertilized with Pi allowing for approximately 80-90% of its maximum growth might still be at risk of the effect. This negative effect becomes more pronounced under more seriously Pi-deficient conditions. Although a number of studies have shown positive crop responses to Phi, these responses are likely to be attributable to the suppression of plant diseases by Phi and/or to Pi formed from oxidation of Phi by microbes. In addition, indirectly providing P by Phi-to-Pi oxidation is not an effective means of supplying P to plants compared with Pi fertilizer. An understanding of these issues will aid the right selection of fertilizer as well as minimize the harmful effects of Phi use on crops.

4) **Nyoman Pugeg Aryantha and David Guest: 2004, Phosphonate (PO) effectiveness against Phytophthora Cinnamomi Rands on Thryptomene Calycina, Banksia grandis and Banksia Spinulosa. Plant Pathology Journal 3(1) 19:25-2004. School of Botany. The University of Melbourne.**

Abstract

The present study shows that Potassium phosphonate has been proven to slow down the growth rate of P. cinnamomi in in vitro. Phosphonate drench as low as 1 g L⁻¹was effective in protecting Thryptomene calycina, Banksia grandis and B. spinulosa in pot and field trials. In glass house trials, concentrations as low as 1 g L⁻¹ (drench) significantly suppressed the P. cinnamomi population. Concentrations over 2 1/2 g L⁻¹ were phytotoxic to all plant species tested. The most sensitive species was B. spinulosa. Phosphonate (5 g L⁻¹) killed all B. spinulosa plants in seven weeks, therefore it must be used with a great care. Phosphonate treatment alone was effective protecting

plants from disease in the field, but did not result in high plant health.

Despite new root growth in pot trials after seven weeks, poor growth was commonly observed on T. calycina after 14 months in field trials. This suggests that phosphonate is not suitable as sole application particularly for the long term. A combination of phosphonate with compost as well as antagonist as an integrated management will be a good alternative for P. cinnamomi management in the future.

5) **Varadarajan D.K., Karthikeyan A.S., Matilda P.D. (2002) Phosphite, an analog of Phosphate, Suppresses the coordinated expression of genes under Phosphate starvation. Plant Physiology 129: 1232-1240.**

Abstract

Phosphate (Pi) and its analog phosphite (Phi) are acquired by plants via Pi transporters. Although the uptake and mobility of Phi and Pi are similar, there is no evidence suggesting that plants can utilize Phi as a sole source of phosphorus. Phi is also known to interfere with many of the Pi starvation responses in plants and yeast (Saccharomyces cerevisiae). In this study, effects of Phi on plant growth and coordinated expression of genes induced by Pi starvation were analyzed. Phi suppressed many of Pi starvation responses that are commonly observed in plants.Enhanced root growth and root to shoot ratio, a hallmark of Pi stress response, was strongly inhibited by Phi. The negative effects of Phi were not obvious in plants supplemented with Pi. The expression of Pi starvation-induced genes such as LePT1, LePT2, AtPT1, and AtPT2 (high-affinity Pi transporters); LePS2 (a novel acid phosphatase); LePS3 and TPSI1 (novel genes); andPAP1 (purple acid phosphatase) was suppressed by Phi in plants and cell cultures. Expression of luciferase reporter gene driven by the Pi starvation-induced AtPT2 promoter was also suppressed by Phi. These analyses showed that suppression of Pi starvation-induced genes is an early response to addition of Phi. These data also provide evidence that Phi interferes with gene expression at the level of transcription. Synchronized suppression of multiple Pi starvation-induced genes by Phi points to its action on the early molecular events, probably signal transduction, in Pi starvation response.

6) **Avila F.W., Faquin V., Araujo J.L., Margues D.J., Ribeiro P.M., Ramos S.J. and others (2011) Phosphite Supply affects Phosphorous nutrition and biochemical responses in maize plants. Australian Journal of Crop Science 5: 646-653**

Abstract

Phosphate (Pi) is the major phosphorus (P) form used for plant nutrition, whereas phosphite (Phi) is effective in controlling important plant diseases caused by Oomycetes pathogens. However, Phi-based products also have been widely marketed as either P fertilizer or biostimulant, such as elicitor of biochemical responses to abiotic and biotic stress agents, although these effects are not as yet well understood. This investigation has aimed to evaluate the effect of Phi supply as part of the P fertilization, and its influence on the guaiacol peroxidase activity and contents of total fenolics and lignin in maize plants.

This study was conducted in an experimental design completely randomized, with 2 P concentrations (52 µ M = low P concentration, and 644 µM = adequate P concentration) and 2 P forms (100% phosphate, and 75/25% as Pi/Phi, respectively). Based on studies of uptake kinetics of the 31P, it was shown Phi inhibits Pi uptake competitively in maize, regardless of the plant Pi status. Replacement of 1/4 of Pi by Phi decreased the biomass production of the plants grown under low Pi supply, but no effect was observed in the plants grown under adequate Pi supply, with the advantage of eliciting biochemical responses to stress agents, such as stimulation of the guaiacol peroxidase activity and lignin biosynthesis.

7) **Mc Donald, A.E., B. Grant, and W.C. Plaxton. 2001. Phosphite (Phosphorous acid): Its relevance in the environment and agriculture and influence on plant phosphate starvation response. Journal Plant Nutrition 24:1505-1519.**

Abstract

Phosphites (H2PO3 -; Phi) are alkali metal salts of phosphorous acid [HPO(OH)2] that are being widely marketed either as an agricultural fungicide or as a superior source of plant phosphorus (P) nutrition. Published research conclusively indicates that Phi functions as an effective control agent for a number of crop diseases caused by various species of pathogenic pseudo fungi belonging to the genus Phytophthora. However, evidence that Phi can be directly used by plants as a sole source of nutritional P is lacking. When Phi is administered in such as way as to allow it to come into contact with bacteria, either associated with plant root systems or in the soil, then the oxidation of Phi to phosphate (HPO4 2-; Pi) may take place. By this indirect method Phi could thus become available to the plant as a P nutrient.

The rates at which this occurs are slow, taking months or as much as a year, depending on the soil type. Phi is not without direct effects on plants itself, as Phi concentrations comparable to those required to control plant infection by pathogenic Phytophthora, or to restrict Phytophthora growth in sterile culture, are extremely phytotoxic to Pi-deprived, but not Pi-fertilized, plants. This is because Phi treatment negates the acclimation of plants to Pi deficiency by disrupting the induction of enzymes (e.g., acid phosphatase) and transporters (e.g., high-affinity plasmalemma Pi translocator) characteristic of their Pi starvation response. Thus, Phi intensifies the deleterious effects of P-deficiency by 'tricking' Pi-deprived plant cells into sensing that they are Pi-sufficient, when, in fact, their cellular Pi content is extremely low. The Phi anion appears to effectively obstruct the signal transduction pathway by which plants (and yeast) perceive and respond to Pi deprivation at the molecular level. The review concludes by citing concerns and recommendations regarding the significant input of Phi into food products and the environment that arises from its extensive use in agriculture and industry.

8) **RALITZA DANOVA-ALT1 , COR DIJKEMA2 , PIETER DE WAARD2 & MARGRET KÖCK ; Martin Luther University of Halle-Wittenberg, Biocenter, 06120 Halle, Germany and 2 Wageningen NMR Center, Dreijenlaan 3, 6703 HA Wageningen, the Netherlands ; Transport and compartmentation of phosphite in higher plant cells – kinetic and 31P nuclear magnetic resonance studies Plant, Cell and Environment (2008) 31, 1510–1521**

Abstract

Phosphite (Phi, H2PO3 -), being the active part of several fungicides, has been shown to influence not only the fungal metabolism but also the development of phosphatedeficient plants. However, the mechanism of phosphite effects on plants is still widely unknown. In this paper we analysed uptake, subcellular distribution and metabolic effects of Phi in tobacco BY-2 cells using in vivo 31P nuclear magnetic resonance (31P-NMR) spectroscopy. Based on the kinetic properties of the phosphate transport system of tobacco BY-2 cells, it was demonstrated that phosphite inhibited phosphate uptake in a competitive manner. To directly follow the fate of phosphate and phosphite in cytoplasmic and vacuolar pools of tobacco cells, we took advantage of the pH-sensitive chemical shift of the Phi anion. The NMR studies showed a distinct cytoplasmic accumulation of Phi in Pi-deprived cells, whereas Pi resupply resulted in a rapid efflux of Phi. Pi-preloaded cells shifted Phi directly into vacuoles. These studies allowed for the first time to follow Phi flux processes in an in vivo setting in plants. On the other hand, the external Pi nutrition status and the metabolic state of the

cells had a strong influence on the intracellular compartmentalization of xenobiotic Phi.

9) **Stehmann, C. and B.R. Grant. 2000. Inhibition of the glycolytic pathway and hexose monophophate bypass by phosphonate. Pesticide Biochemistry and Physiology 67:13-24.**

Abstract

Previous studies have suggested that the phosphonate ion (Phi), an isostere of phosphate, might be a general inhibitor of enzymes which are allosterically regulated by phosphate or which have a requirement for divalent cations. In this paper, the capacity of Phi to inhibit selected enzymes of this type from Phytophthora palmivora is compared with its effects on the same enzymes isolated from other organisms, in particular from Saccharomyces cerevisiae, which are widely used in linked assays of many enzymes. It was found that Phi inhibited the activity of the enzymes from P. palmivora investigated, though to different degrees. IC50 values (concentration required to inhibit enzyme activity by 50%) for Phi ranged from 0.74 ± 0.07 mM (NAD-dependent glyceraldehyde-3-phosphate dehydrogenase) to 116.1 ± 7.3 mM (6-phosphogluconate dehydrogenase).

Among the activities tested glucose-6-phosphate dehydrogenase activity from P. palmivora was significantly more sensitive to Phi than the same enzyme from yeast, although its absolute IC50 value (29.0 ± 3.4 mM) was high in comparison to most fungicides. It was also found that the auxiliary enzymes from rabbit muscle (aldolase, glycerophosphate dehydrogenase, and triosephosphate isomerase) and yeast (glucose-6-phosphate dehydrogenase) used in enzyme-linked assays were all sensitive to Phi, giving IC50 values between 7.7 ± 0.4 and 73.6 ± 2.0 mM, a sensitivity comparable to the other enzymes under investigation. Inorganic phosphate also inhibited the activity of the enzyme glucose-6-phosphate dehydrogenase and the aldolase/triosephosphate isomerase/glycerophosphate dehydrogenase mixture with IC50 values of 108.3 ± 7.7 and 13.0 ± 0.6 mM, respectively. In conclusion, Phi inhibition was found to be widespread, supporting the hypothesis that Phi may inhibit several enzymes rather than acting at a single unique site. It was also found that the coupling enzymes used in many of the assays for these enzymes were themselves susceptible to Phi and phosphate inhibition, which must be taken into account in the interpretation of the results obtained with this type of assay.

10) **Carla A. Ticconi, Carla A. Delatorre, and Steffen Abel. Attenuation of Phosphate Starvation Reponses by Phosphite in Arabidopsis. Plant Physiol, November 2001, Vol. 127, pp. 963-972.**

Abstract

When inorganic phosphate is limiting, Arabidopsis has the facultative ability to metabolize exogenous nucleic acid substrates, which we utilized previously to identify insensitive phosphate starvation response mutants in a conditional genetic screen. In this study, we examined the effect of the phosphate analog, phosphite (Phi), on molecular and morphological responses to phosphate starvation. Phi significantly inhibited plant growth on phosphate-sufficient (2 mm) and nucleic acid-containing (2 mm phosphorus) media at concentrations higher than 2.5 mm. However, with respect to suppressing typical responses to phosphate limitation, Phi effects were very similar to those of phosphate.

Phosphate starvation responses, which we examined and found to be almost identically affected by both anions, included changes in: (a) the root-to-shoot ratio; (b) root hair formation; (c) anthocyanin accumulation; (d) the activities of phosphate starvationinducible nucleolytic enzymes, including ribonuclease, phosphodiesterase, and acid phosphatase; and (e) steady-state mRNA levels of phosphate starvation-inducible genes. It is important that induction of primary auxin response genes by indole-3-acetic acid in the presence of growth-inhibitory Phi concentrations suggests that Phi selectively inhibits phosphate starvation responses. Thus, the use of Phi may allow further dissection of phosphate signaling by genetic selection for constitutive phosphate starvation response mutants on media containing organophosphates as the only source of phosphorus.

11) **Arne M. Ratjenl, Joska Gerendas. A critical assessment of the suitability of phosphite as a source of phosphorous. Journal of Plant Nutrition and Soil Science, Volume 172, Issue 6, Pages 821-828, December, 2009.**

Abstract

Marketing of phosphite-containing preparations for foliar application, together with recent reports of positive yield responses, has revived the question as to whether phosphite (HPO3-) is a suitable P source for plants. Two experiments using zucchini (Cucurbita pepo L. convar. giromontina) have been conducted to evaluate the P-nutritional effect of phosphite either provided via the substrate or as a foliar spray. Plants grown in a P-deficient substrate were severely damaged when phosphite was applied as foliar fertiliser and more drastically when provided via the substrate. Growth of P-deficient plants receiving phosphite as a foliar spray was impaired in a dose-dependent manner after foliar P application (concentrations 0.0, 0.9, 2.7, and 4.5 g P L^{-1}), while foliar provision of phosphate

improved plant growth and yield. In the youngest leaves of phosphite-treated plants, which had developed after foliar spray, phosphite accumulated to considerable extent, reaching a similar concentration as phosphate at tissue level. These results confirm that P-deficient plants are very sensitive to phosphite, which represents a nutritionally ineffective form of P. It should thus not be considered as a form of P suitable for fertiliser manufacture.

12) **Central Sugarcane Research Station, Padegaon**

All-India Coordinated Research project on Sugarcane [AICRP (S)], Zonal Research Centre, Peninsular Zone CSRS Padegaon, Mahatma Phule Agricultural University - Rahuri, Ahamadnagar district, Maharashtra.
Tested the impact of PSAP on yield and quality of sugarcane in a tropical region. Reports confirmed 18.75 t/ha. increase in sugarcane yield and 0.26% improvement in CCS recovery leading to 3.3 t/ha. additional sugar production with the sprays of PSAP. Studies also revealed that even after 50% reduction in recommended P and K fertilizers, application of 3 kg PSAP per acre given in split sprays increased sugarcane yield and improved sugar recovery.

13) **ICAR- National Research Center for Grapes, Pune**

PSAP (ProPhite) tested by ICAR- NRCG based on the request and samples submitted by MRDBS, Maharashtra Rajya Draksha Bagayatdar Sangh, grape growers Association, on the contents of pesticides and P and K percentage in ProPhite (PSAP). Test reports revealed no content of pesticides when tested for 996 chemicals. The content of P and K in PSAP was found to be 16.27% and 30.23% respectively, which was different the contents of P and K in mono and/or di potassium phosphate P: 25.8% and K : 32% and P : 19.6% and K : 49%. Based on the content of P and K in PSAP, it was certified that PSAP is not analogous to potassium phosphate or mono and / or di potassium salt of phosphorous acid.

14) **UPCSR- Uttar Pradesh Council of Sugarcane Research, Shahjanpur**

Tested the impact of PSAP further for two years at two locations in central as well as easten Uttar Pradesh, i.e. in a sub-tropical region. The test report revealed very impressive impact of PSAP on yield and quality in the local sugarcane variety and even in under different geo conditions. Sugarcane yield increased by as much as 24.4 tonnes per hectare and recovery improved in CCS percentage by 0.5% unit. Improvement in yield and CCS percentage meant that sugar production increased by 3.47 tonnes per hectare with an estimated increase in alcohol production by

275 liter per hectare and a co-generation of 1220 units per hectare with additional bagasse availability.

15) **ICAR- National Research Center for Grapes, Pune**

Tested ProPhite (PSAP) in comparison with potassium phosphite for the control various diseases grapes. PSAP proved far superior in controlling various diseases like downy mildew and anthracnose in grape. It was also observed that split sprays of PSAP can reduce fungicide sprays by 50 %. PSAP also improved the yield by 34.80% to 68.66% which applied singly in combination with fungicides. PSAP was also shown as analogous to potassium phospite either as mono-di potassium salt of phosphorous Acid.

16) **Research Article on Management of Downy Mildew of Cucumber by Lowering Toxic Fungicide Applications**

The experiment was conducted to decrease fungicide applications for the management of downy mildew of cucumber. Different combinations of PSAP, fungicides and micronutrients were tested. The combination containing a fungicide and PSAP were more effective than fungicides, micronutrients applied singly or in combinations. PSAP and fungicide controled the downy mildew disease most effectively and increase the yield by 40 %. PSAP applied singly also effectively controlled the downy mildew of cucumber and increased the yield of cucumber by 25% the results clearly showed that, yield can be increased by 40% with 50% reduction in fungicide applications or fungicides can be replaced with PSAP. None of the attempted treatments showed any kind of phytotoxicity on cucumber crop.

17) **RVKVV – Gwalior – College of Horticulture – Mandsaur**

The field trials were conducted to evaluate the PSAP against Downy mildew and Powdery mildew. PSAP tested at AICRP M & AP research filed, Mandsaur for evaluation of bio-efficacy of PSAP on Opium Poppy (Papaver somniferum). The Field trials have been conducted during 2018- 2019, 2019-2020 and 2020 – 2021 for three years. From above experiment it is evident that the foliar spray of 50% reduction of recommended spray for the crop + with PSAP @ 6 gm / liter shows maximum reduction in disease incidences and maximum increase in seed yield, latex and husk yield without any symptom of phytotoxicity.

18) **NSI – National Sugar Institute Kanpur**

Collaborative Research Project was conducted for testing of PSAP - bio-efficacy on sugarcane for two years in two plantations and one ratoon crop. On the basis of above study, it is concluded that application of PSAP only through foliar sprays (four prays at 60, 75, 90 and 120 DAP) gave significantly better results with all doses of PSAP than control (without PSAP application treatment). Foliar application of PSAP @ 12.5 kg per hectare at different periods after planting along with 100 per cent recommended dose of NPK (180:80:80) applied in sugarcane cultivation is helpful in improved growth, juice purity and higher net return with improved benefit cost ratio.

19) **CSAUT - Chandra Shekhar Azad University of Agriculture & Technology, Kanpur**

Testing of PSAP – "Potassium salt of active phosphorus" a research molecule on sugarcane for 2019-20 and 2020 – 2021 two plantations and one ratoon crop season. For both yield and quality aspects of sugarcane by the application of various dosed of PSAP, it can be concluded that application of PSAP @ 12.5 Kg/ha with 180: 80:80 Kg N: P: K as foliar spray on sugarcane crop at 60, 75, 90 and 120 Days After Planting gave significant higher yield of cane along with best quality of juices and higher Brix.

20) **ICAR - IISR – On AICRP in Soybean, Khandwa Road, Indore (M.P.)**

"Bio-efficacy evaluation of potassium salt of active phosphorus (PSAP) on soybean" Trial conducted at ten (10) location/centers of AICRP Soybean (Agronomy) during kharif 2020 and 2021.

21) **Guangxi Academy of Agricultural Sciences - China**

Predication of Photosynthetic Leaf Gas Exchange of Sugarcane (Saccharum spp) Leaves in Response to Leaf Positions to Foliar Spray of Potassium Salt of Active Phosphorus under Limited Water Irrigation. PSAP role in limited water condition is accessed. In conclusion, overall, the present results revealed that the PSAP application might be an efficient technique for improving the tolerance of sugarcane plants subjected to limited water irrigation. It also up regulated the photosynthetic capacity by protecting the negative impacts of sugarcane plants during limited irrigation. Taken together, PSAP has a significant role in sugarcane cultivation under insufficient water availability for irrigation and its optimum dose will be supportive in mitigation of limited irrigation in a variety of crops for sugar and bio-energy sectors. This combination also greatly improved the photo-

synthetic activities and plant growth. However, to suggest an optimum dose of PSAP concentration, a large-scale demonstration under field conditions should be assessed in later studies. Krishan K. Verma, Xiu-Peng Song, Chhedi Lal Verma, Mukesh Kumar Malviya, Dao-Jun Guo, Vishnu D. Rajput, Anjney Sharma, Kai-Jun Wei, Gan-Lin Chen, Sushil Solomon, and Yang-Rui Li

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