

**Effect of foliar application of nano phosphorus  
on plant growth, seed yield and quality of rice  
(*Oryza sativa* L.)**

**A**

***Thesis submitted to the  
Odisha University of Agriculture and Technology  
in Partial fulfilment of the Requirement for the degree of  
Master of Science in Agriculture  
(Seed science and Technology)***

***By***

***ANIL KUMAR MOHANTY***

***Adm. No. 18122N06***



**DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY  
COLLEGE OF AGRICULTURE  
ODISHA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
BHUBANESWAR- 751003, ODISHA**

**2020**

## CERTIFICATE OF ANTI-PLAGIARISM

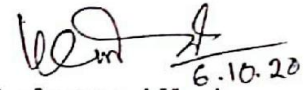
This is to certify that the M. Sc. (Ag) thesis of Anil Kumar Mohanty, Adm No. 18122N06, M. Sc. (Ag) scholar, Department of Seed Science and Technology, College of Agriculture, OUAT, Bhubaneswar has been checked for anti-plagiarism by using Turnitin web portal and similarity index was found within 15% levels (From Abstract to Summary and Conclusion) as prescribed by OUAT.

Anil Kumar Mohanty.

Student

  
Chairman

Professor & Head  
Seed Science & Technology Deptt.  
College of Agriculture  
O.U.A.T., BBSR - 3

  
6.10.20

Professor and Head

Professor & Head  
Seed Science & Technology Deptt.  
College of Agriculture  
O.U.A.T., BBSR - 3



**ODISHA UNIVERSITY OF AGRICULTURE & TECHNOLOGY  
DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY  
COLLEGE OF AGRICULTURE  
BHUBANESWAR**

**Dr. K. C. Muduli**  
Professor and Head  
Department of Seed Science and Technology,  
College of Agriculture, OUAT,  
Bhubaneswar-751003

Bhubaneswar  
Date: 31.08.2020

**CERTIFICATE-I**

This is to certify that the thesis entitled "**Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.)**" submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (SEED SCIENCE AND TECHNOLOGY)** to the Odisha University of Agriculture and Technology, Bhubaneswar is a faithful record of *bona fide* and original research work carried out by **ANIL KUMAR MOHANTY, Adm. No. 18122N06** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

**Dr. K.C. Muduli**  
Chairman  
Advisory Committee




## CERTIFICATE-II

This is to certify that the thesis entitled “Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.)” submitted by ANIL KUMAR MOHANTY, Adm. No. 18122N06 to the Odisha University of Agriculture and Technology, Bhubaneswar, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE (SEED SCIENCE AND TECHNOLOGY)** has been approved by the Student’s Advisory Committee and the External Examiner.

### ADVISORY COMMITTEE

**CHAIRMAN:**

**Dr. K.C. Muduli**  
Professor and Head  
Department of Seed Science and Technology  
College of Agriculture,  
OUAT, Bhubaneswar

  
14.9.20

**MEMBERS:**

**Dr. A.K. Dash**  
Professor  
Department of Soil Science and  
Agricultural Chemistry  
College of Agriculture,  
OUAT, Bhubaneswar

  
14/09/2020

**Mr. A.K. Behera**  
Assistant Professor  
Department of Agronomy  
College of Agriculture,  
OUAT, Bhubaneswar


  
14/09/2020

**Dr. S. Mohanty**  
Assistant Seed Research officer,  
Seed Technology Research,  
AICRP-NSP(Crops)  
College of Agriculture,  
OUAT, Bhubaneswar

  
14/09/2020

**External Examiner**

**(Name and Designation)**

  
Dr. Laxmi Anja Sahas  
Sr. Scientist (Seed Tech)  
ICAR-CIWA, Bhubaneswar

## ACKNOWLEDGEMENT

Gratitude takes three forms, “A feeling from the heart, an expression in words and giving in return.....”

A journey is easier when worked together. Writing this thesis has been fascinating and extremely rewarding. During this course of my journey, I have been accompanied and supported by many people who helped me along this long but fulfilling road. Throughout the entire period of my research work, I have been blessed enough to have those caring well-wishers around me. I take this opportunity to express my sincere gratitude to each of them.

Any tedious task is made light and smooth by God’s grace. At this moment, I would remember **Lord Jagannath**, who has made each impossible work into a reality in my life and has given me enough strength and courage to complete this task successfully.

My words leave no bound to express gratitude towards **my beloved parents** for being there whenever needed. Their blessings, care, love, understanding and support are the source of constant spirit and inspiration throughout my entire career. I convey my sincere acknowledgement to my lovely father and innocent and most caring mother for making the journey smooth and successful through their constant support throughout the entire research work.

It was always immense and immeasurable pleasure to applaud the auspicious personality who has the character of benevolence, consummate and care taking in others welfare. Here I am in hunt for words to express my pleasurable feelings and thankfulness to my well-wisher cum chairman of my advisory committee **Dr. K.C. Muduli**, Professor and Head, Department of Seed Science and Technology, College of Agriculture, OUAT, Bhubaneswar for his level of guidance, lively encouragement, constructive criticism and untiring help at every stage of my research work which is far beyond the call of duty. It has been my privilege and good fortune to work under him and consider myself to be extremely lucky to have him as my guide. My experience with working under his guidance will always remain as a unforgettable memory in my whole life.

It is my privilege to express my sense of reverence, gratitude and thanks to **Dr. A.K. Dash**, Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, OUAT, Bhubaneswar for being a member of my advisory committee as well as for his able guidance, valuable suggestions and ceaseless help and providing all the facilities timely as and when required. I just find it difficult to forget the ease with which he could induce the confidence and optimism in me without which this work would have been far from reality.

I am truly indebted and thank profusely to **Mr. A.K. Behera**, Assistant Professor, Department of Agronomy, College of Agriculture, OUAT, Bhubaneswar and **Dr. S. Mohanty**, Assistant Seed Research Officer, Seed Testing and Research, AICRP-NSP(Crops), OUAT, Bhubaneswar for being members of my advisory committee and their constant encouragement, valuable suggestions and kindness.

I feel greatly indebted and convey my profound sense of gratitude to my esteemed teachers and non-teaching staffs of Department of Seed Science and Technology, **Dr. S.K. Swain**, Professor and Head (Retd.), Department of Seed Science and Technology, **Dr. D. Dash**, Assistant Seed Research Officer (Seed Entomology), **Mrs. Anita Priyadarsini**, Assistant Seed Research Officer (Seed Pathology), **Jayanta Sir**, **Priti Madam**, **Braja Sir** and **Rabi sir** for their precious help, sincere cooperation and active support during the period of my experiment for which I must thank all of them sincerely.

I do express my sincere gratitude to the **Hon'ble Vice-Chancellor, Dean, PGF-cum-DRI and Dean**, College of Agriculture, OUAT, Bhubaneswar, for providing all sorts of facilities to conduct the research work.

I equally avail this opportunity to express my deep sense of gratitude to **Dr. S.N. Jena**, Professor, Department of Agronomy and **Dr. Sannat Diwedi**, Assistant Professor, Department of Agronomy, **Dr. I.C. Mohanty**, Professor, Department of Agricultural Bio-Technology, College of Agriculture, OUAT, Bhubaneswar for their never ending enthusiasm, valuable advices and escort extended to me for the better study of the project.

I also thank to field assistant **Nirmal bhai** who is a constant part of my research work and due to his constant help, I was able to do my research work easily, smoothly and successfully.

I would be at fault if I do not remember my seniors. I sincerely admire the contribution of my seniors **Natha bhai, Swastideepa didi, Biplab bhai, Jigyansha didi, Ankit bhai, Sunil bhai, Rudra bhai**. I am strongly beholden to my seniors for their benevolent presence to help me out whenever needed during this investigation.

I am thankful to my classmates **Madhusmita, Subhalaxmi, Debasis, Atish, Arijit, Bijay, Sourav, Ramesh, Sushma, Ananya, Amit, Uttam** and my dearest juniors **Yoshabanta, Manas, Bikash, Soumya** and **Shukla** for timely help and support in various activities involved throughout my research work and preparation of this thesis.

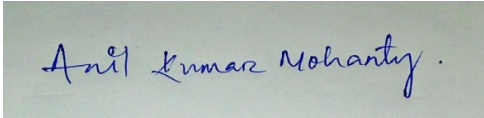
Here, I would like to thank my dearest friend **Satyajit Dash**, who needs special mention for giving me immense strength and created positive vibes in me to make my hard path so smooth. Without you and your support this investigation would not be successful.

I also thank my younger brother **Sunil** and sister **Anita** for their love, affection, care, advices and support without which this thesis cannot be a successful one.

Last but not the least, I take this opportunity to express my gratitude to all who have helped me directly or indirectly throughout the period of my research to complete the thesis. These two years of PG would not be successful without all the efforts I received through the journey. I really thank each and everyone from the core of my heart for the successful completion of this galvanic experience. I express deep apology if I forgot to mention any.

Bhubaneswar

Date: 31.08.2020



Anil Kumar Mohanty.

# CONTENTS

CHAPTER	PARTICULAR	PAGE
I	INTRODUCTION	1-5
II	REVIEW OF LITERATURE	6-20
III	MATERIALS AND METHODS	21-31
IV	RESULTS	32-51
V	DISCUSSION	52-57
VI	SUMMARY AND CONCLUSION	58-64
	REFERENCES	i-xi

---

# LIST OF TABLES

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
1	Initial nutrient status of soil of the experimental plot.	22
2	Meteorological data during the period of study (July to December, 2019)	23
3	Effect of foliar application of nano-phosphorus on days to 50% flowering and days to maturity in rice cv. Mandakini.	33
4	Effect of foliar application of nano-phosphorus on plant height, total tillers/hill, effective tillers/hill and totalchlorophyll content in rice cv. Mandakini.	34
5	Effect of foliar application of nano-phosphorus on panicle length and no. of spikelets/panicle in rice cv. Mandakini.	36
6	Effect of foliar application of nano-phosphorus onfilled grains/ panicle (%) and unfilled grains/panicle (%) in rice cv. Mandakini.	37
7	Effect of foliar application of nano-phosphorus on 1000 seed weight, seed yield/hill and seed yield/hain rice cv. Mandakini.	39
8	Effect of foliar application of nano-phosphorus on seed moisture(%) in rice cv. Mandakini.	40
9	Effect of foliar application of nano-phosphorus on electrical conductivity of seed leachate (dS/m) and germination(%) in rice cv. Mandakini.	42
10	Effect of foliar application of nano-phosphorus on first count and field emergence in rice cv. Mandakini.	43
11	Effect of foliar application of nano-phosphorus on seedling shoot length and root length and seedling length in rice cv. Mandakini.	45
12	Effect of foliar application of nano-phosphorus on seedling dry weight and seed vigour indices in rice cv. Mandakini.	47
13	Effect of foliar application of nano-phosphorus on germination (%) and field emergence after accelerated ageing in rice cv. Mandakini.	48
14	Effect of foliar application of nano-phosphorus on seed vigour indices after accelerated ageing in rice cv. Mandakini.	50
15	Reduction (%) in germination and seed vigour indices after accelerated ageing in rice cv. Mandakini.	51

---

## ABBREVIATIONS USED

AA	:	accelerated ageing
ANOVA	:	analysis of variance
$^{\circ}\text{C}$	:	degree Celsius
Cm	:	centimetre
CV	:	coefficient of variation
CD	:	critical difference
dS/m	:	DeciSiemens per metre
<i>et al.</i>	:	co-workers
etc.	:	<i>et cetera</i> (and other things)
e.g.	:	<i>exempli gratia</i> (for example)
Fig.	:	Figure
G	:	gram
Ha	:	hectare
i.e.	:	that is
FAO	:	Food and Agricultural Organization
Kg	:	kilogram
$\text{Kg ha}^{-1}$	:	kilogram per hectare
Mg	:	milligram
$\text{mg g}^{-1}$ FW	:	milligrams per gram of fresh weight
NUE	:	Nutrient Use Efficiency
%	:	percentage
SVI-I	:	Seed Vigour Index-I
SVI-II	:	Seed Vigour Index-II
SEm	:	standard error of mean
viz.	:	videlicet (namely)
Ppm	:	parts per million

# ABSTRACT

A field experiment entitled effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.) was conducted at Central Research Farm, Regional Research and Technology Transfer Station, Coastal Zone, OUAT during Kharif 2019 in collaboration with Dept. of Soil Science and Agricultural Chemistry, OUAT, Bhubaneswar, using rice variety Mandakini in RBD with three replications and seven treatments viz. T<sub>1</sub>- Control, T<sub>2</sub>- 100% STD (75:37.5:37.5 NPK kg/ha), T<sub>3</sub>-100% STD + spray of water (500 litre/ha) at 14 DAT, T<sub>4</sub>- 100% STD + spray of nano-P (40ml/litre) at 14 DAT, T<sub>5</sub>-100% STD + 2 sprays of nano-P(40ml/litre) at 14 and 28 DAT, T<sub>6</sub>-100% NK & 75% P of STD + 2 sprays of nano-P(40ml/litre) at 14 and 28 DAT, T<sub>7</sub>- 100% NK & 50% P of STD + 2 sprays of nano-P(40ml/litre) at 14 & 28 DAT. During the course of investigation, the effects on different treatments were studied after foliar application of nano-P in respect of various plant growth, seed yield and its attributes as well as seed quality parameters including storability of seeds.

Treatments with 100% STD with 2 sprays of nano-P(T<sub>5</sub>) showed significantly enhanced effect on plant growth parameters such as days to 50% flowering(83.33 days), days to maturity(107.3days), total tillers/hill(8.87), plant height(119.5cm) and total chlorophyll content of leaves(3.61mg/g FW). The treatments with 100% STD with 1 or 2 spray of nano-P had taken similar duration to reach

50% flowering. 100% STD had similar duration to reach 50% flowering as 75% STD for P+2 sprays of nano-P, while it was earlier in maturity. Yield components were positively influenced by the foliar spray of nano-P such as effective tillers/hill(8.07), panicle length(24.73 cm), no of spikelets/panicle(133.4), filled grains/panicle(91.63%), unfilled grains/panicle(8.37%),1000-seed weight(25.13g) as well as seed yield/hill(15.65g), seed yield/ha(26.23q) and HI(54.49%) with the treatment of 100% STD +2 sprays of nano-P (T<sub>5</sub>) which registered the highest but lowest in control. The application of only 100% STD had similar effect as 50, 75 and 100 % STD for P + 1 or 2 sprays of nano-P except for yield/ha. The seed yield/ha was highest (26.23 q/ha) in 100% STD +2 sprays of nano-P (T<sub>5</sub>) showing 52.14% advantage over control (17.24 q/ha) whereas the treatment 75% STD for P + 2 sprays of nano-P (24.72 q/ha) had similar yield level with 100% STD (24.94 q/ha), but application of 50% STD for P+2 sprays of nano-P showed reduced yield (23.26 q/ha) suggesting that 2 sprays of nano-P with conventional 75% STD had similar effect as 100% STD. The increase in yield may be due to the cumulative result of increase in the yield attributes like effective tillers/hill, filled grains/panicle and 1000 seed weight. Most of the seed quality parameters, like germination, field emergence, shoot-root length, seedling length and dry weight, SVI- I & II were influenced by nano treatments except seed moisture(%). However, all treatments except T<sub>7</sub> had positive response on EC, field emergence, root and shoot length and seedling length indicating that 50% STD for P with 2 sprays of nano-P(T<sub>7</sub>) could not meet the plant's nutritional requirements for these parameters. 100% STD with 2 sprays of nano-P showed highest and control had the lowest result for these traits.100% STD (T<sub>2</sub>) and 75% STD for P + 2 sprays of nano-P (T<sub>6</sub>) were at par for SVI-I & SVI-II. All treatments after accelerated ageing (AA) of seeds showed reduced values as compared to normal fresh seeds for seed germination(%), field emergence, SVI-I & II. For most of the parameters, the sole application of 100% STD registered similar results as with 75% or 100% STD for P + 2 sprays of nano-P. The reductions (%) of these parameters after AA were highest in control and the treatment with 50% STD for P + 2 sprays of nano-P.Minimal reduction was recorded with 100% STD + 2 sprays of nano-P as compared to control indicating better storability of seeds.

Considering the growth parameters, yield performance and seed quality attributes, it may be concluded that in almost all cases the application of 100% STD @ 75:37.5:37.5 NPK kg/ha + 2 sprays of nano-P (40 ml/litre) at 14 & 28 DAT was found to be most effective in giving better plant growth, higher seed yield (26.23 q/ha) and better seed quality parameters in rice cv. Mandakini, while the treatment of 75% STD for P + 2 sprays of nano-P recorded similar result (24.72 q/ha), coupled with almost similar or superior seed quality parameters as compared to 100% STD (24.94 q/ha). So, if nanofertilizer could be made available at similar price of conventional fertilizers, the use of nanofertilizer will reduce the cost of seed production and pollution will be minimized.

Rice or Paddy (*Oryza sativa* L.), family- Poaceae, is one of the most important cereal crops of the world, grown in wide range of climatic zones, to nourish the mankind. Rice is the second most consumed cereal worldwide and is one of the world's major crops, especially in Asia, because it contains proteins, carbohydrates, vitamins and many important nutrients and compounds that have a significant impact on health and reduce the risk of disease, especially cancer. (Aguilar-Garcia *et al.* 2007 and Liu 2007)

Rice is an important food grain for majority of the world population and in India. It provides about 31% calories, 17% protein & 7.3% protein in milled rice, for which it is considered as a staple food for 88.2% of Indian population. Within rice growing countries, India has the largest area 100m.ha under rice in the world. In respect of production, India stands second with 116.42m.tons of paddy which is 22.25% of the total world production. However, the average yield potentiality in India is lowest, i.e., 2.66tons/ha (Directorate of Economics and Statistics, DAC&FW, 2019).

In India rice is grown in almost all the states under widely varying conditions of altitudes and climates. Its cultivation in India is extended from 19°48'N latitude from the mean sea level to as high as 6 metres. Odisha is an agrarian state accounts for 3.71m.ha area (8.47% of all India) with 7.31m.tons (6.28% of all India production) and yield potential is 1.97tons/ha (Directorate of Economics and Statistics, DAC&FW, 2019).

The misfortune of natural calamities always imposes threat to the production and productivity of crops in Odisha state. In the present scenario, with increasing population and decreasing per capita land area, the productivity of the crops will be reaching to the bottom soon. Increase in quality seed production of crops will be a definite solution for the enhancement of the social and economic status of the farming community. The chief task of Seed Science is to produce quality seed with high vigour to conquer this peril.

Considering the increasing population growth of India, the expected rice requirement must be reached to a level of 160million metric tons by 2050AD (Swain *et al.* 2017). To provide food for such enormously rising population, it is so much

necessary to boost the agricultural productivity. Agricultural inputs like chemical fertilizers are very much important for higher plant growth, development and yield of high yielding and fertilizer responsive crop varieties. Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice (Alam et al., 2009). But, most of the applied fertilizers are unavailable to plants due to several factors such as leaching, fixation in soil, volatilization losses, degradation by photolysis, hydrolysis and decomposition, etc. Also the application of conventional fertilizers at a higher dose for a longer period of time in agricultural field has brought many environmental problems not only in our country but also globally. Green revolution had led to the increased consumption of chemical fertilizers which resulted in the higher productivity on one hand, on the other hand, it also caused environmental hazards (Mahilet *al*, 2019). Thus the development of a new compensatory technology for this purpose is a crying need for present situation. In order to reduce nutrient losses with a smart delivery technique, nanotechnology and nanoparticles in fertilization is an emerging trend to boost the crop yield as well as to deal with problems of low fertilizer use efficiency, multi-nutrient deficiencies, excessive fertilization and deteriorating soil organic matter (Lal & Liu, 2014).

Nanotechnology is the revolutionary technology where the particle size ranges between 1 and 100 nm at least in one dimension. Due to their high surface area, high reactivity and better penetration into the cell, these can activate plant and microbial activities resulting more nutrient use efficiency. Also, it can offer safer, cost effective and smart products that will find wide applications in agriculture (Tarafdar *et al*. 2015). Nano-fertilizers are also the effective means of increasing the quantity and quality of the yield in conditions unsuitable for expansion in the reclamation of agricultural land, especially in the absence of water resources (Baruah and Dutta, 2009). After adding nano-fertilizer, there is release of the ions of elements containing a high surface area as well as high energy and effective penetration of the cell wall, they enter directly into the metabolism of food. (Naderi and Danesh-Sharaki, 2013).

Nanofertilizers are synthesized or modified form of traditional fertilizers, fertilizers bulk materials or extracted from different vegetative or reproductive parts of the plant by different chemical, physical, mechanical or biological methods with the help of nanotechnology used to improve soil fertility, productivity and quality of

agricultural produces. Nanoparticles can be made from fully bulk materials. At nano-scale, physical and chemical properties are different from bulk material.

The nano-coated substances enhance the penetration via stomata with a size exclusion limit above 10 nm (Eichert et al., 2008; Pérez-de-Luque, 2017). In addition to this, nano-carriers deliver the nutrients in the right place and right time which reduce the extra amount of active chemicals deposited into the plant system and increase the nutrient use efficiency. Nano-fertilizers have high surface area, sorption capacity, and controlled-release of kinetics to targeted sites, and have been considered as smart delivery system (Rameshaiah et al., 2015; Solanki et al., 2015).

The nutrient use efficiency (NUE) of conventional fertilizers is very low. Nanofertilizers can improve crop growth, yield and quality parameters with increased nutrient use efficiency, reduction in wastage of fertilizers and cost of cultivation. Hence, to overcome all these drawbacks in a better way, nanotechnology can be a ray of hope. (Mahil *et al.* 2019). Significant increase in yields has been observed due to foliar application of nanoparticles as fertilizer (Tarafdar *et al.* 2015). The higher NUE and significantly lesser nutrient losses of nanofertilizers lead to higher productivity (6–17%) and nutritional quality of field crops. In rice, Nanofertilizer + Urea is reported to have yield increment of 8.5-10.2% (Iqbal, 2019).

Phosphorus being the major nutrient plays a vital role in energy transformation, uniform grain filling, grain quality (protein and oil production) and higher yield (Choudhary *et al.* 2018). Phosphorus helps in root, flower and fruit development. It is very much important for quality seed production. Phosphorus deficit is a most important restrictive factor in plant growth and recognition of mechanisms that increase plant phosphorus use efficiency is important (Alinajoati and Mirshekari, 2011). Among macronutrients, phosphorus (P) deficiency is a common factor hindering yield and crop quality worldwide. Phosphorus application to rice increased P accumulation in soil but did not consistently increase rice yields because flooding decreased soil P sorption and increased P diffusion resulting in higher P supply to rice relative to wheat (Dong et al., 2015). About 80–90% of phosphorus of the used normal fertilizers cannot be absorbed by plants and is lost to the environment, causing substantial economic and resource losses and very serious environmental pollution (Saigusa, 2000). So, fertilizer P application is essential to

meet the crop demand as well as for the maintenance of soil P level. The amount of P fertilizer to be applied depends on soil P status, P adsorption in soils, environmental conditions and crop management practices. 20% more yield can be obtained with adequate application of phosphorus fertilizer (Abdel-Aziz *et al.*, 2016). Also, P is essential for enhancing seed maturity and seed development (Ziadi *et al.*, 2008), improved photosynthetic activity and transport to the ripening grains (Hadis *et al.*, 2018) and heavier grains (Crista *et al.*, 2012; Rietra *et al.*, 2017).

For intensive crop production which aims at high levels of productivity, supplemental plant nutrition is needed, which may be given through soil application and or foliar application. Nutrients through soil application is the most common practice including many limitations with respect to availability of nutrients to the plants. The inorganic nutrients get fixed in soil in insoluble forms and also subjected to leaching by rainfall or irrigation water (Alshaal and El-Ramady, 2017). **Foliar application** overcomes these limitations. In addition to that, foliar feeding has proved to be the fastest way of correcting nutrient deficiencies and increasing yield and quality of crop products (Roemheld and El-Fouly, 1999) and it also minimizes environmental pollution and improves nutrient utilization by reducing the amounts of fertilizers added to the soil (Abou-El-nour, 2002).

In agriculture, the quality of seed has prime importance as high quality seed will ensure a healthy crop stand in the field and finally leading to the higher yield. In view of such circumstances, systematic research efforts are to be made to find out an optimum combination of the inorganic fertilizers with different nano-fertilizers which are eco-friendly, have potential to reduce usage of conventional fertilizers besides raising seed crop output in rice. Irrespective of crops, the sowing quality of seed plays a pivotal role for successful crop production. Hence, suitable technology should be adopted to harvest and recover more quantity of seeds of high quality in any seed production program. Storability is another important attribute of harvested seeds. Both pre-harvest as well as post-harvest care would ensure the storability of harvested seeds during seed production. Further, the area under the crop is increasing every year and new improved varieties are being released in Odisha as well as the country. Its cultivation depends on the selection of suitable variety and supply of quality seeds to the farmers. Since the seed requirement depends on the area occupied by the crop, the demand for good quality seeds of those varieties is increasing day by day.

Keeping the above facts in mind, the present field experiment entitled, “Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice(*Oryza sativa* L.)”was undertaken to exploit the potential use of nano phosphorus on plant growth, yield and seed quality of rice with the following objectives:

1. To study the effect of foliar application of nano phosphorus on plant growth parameters of rice
2. To evaluate the effect of foliar application of nano phosphorus on seed yield and its attributes of rice
3. To assess the effect of foliar application of nano phosphorus on seed quality parameters of rice

Nano-fertilizers have become most advanced approach in agricultural research nowadays. Due to the limitation in cultivable lands and water resources, the development of agriculture sector is only possible by increasing of nutrient use efficiency with the minimum damage to production site through effective use of modern technologies. Nano-fertilizers can be an important tool in agriculture to improve crop growth, yield and quality parameters with increase nutrient use efficiency, reduce wastage of fertilizers and cost of cultivation.

In this chapter, the literature collected from different sources with respect to “Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.)” has been reviewed to understand the present importance of use of nano phosphorus in agriculture. Literature on use of nano phosphorus is minimal, therefore literature of some other nanoparticles have also been included in this chapter to emphasize certain point of view.

### **2.1. Effect of nano fertilizers on plant growth parameters**

Zinc has an effect on synthesizing of natural auxin (IAA) and also can activate many enzymes involved in the biochemical pathways such as carbohydrate metabolism, protein metabolism, growth regulator metabolism, pollen formation and maintaining the integrity of biological membranes (Alloway, 2008; El-Tohamy and El-Greadly, 2007; Cakmak, 2000). Thus, the plant growth promoting hormone contents get increased with the application of nano Zn fertilizer.

Foliar application of nano-iron fertilizer increased the growth of forage corn and *Ocimum basilicum* L. because of enhanced production of crude protein and soluble carbohydrates (Sharifi et al., 2016; Peyvandi *et al.*, 2011).

Foliar application of nTiO<sub>2</sub> has been recorded significantly higher chlorophyll content, carotenoids and anthocyanins of maize crop, which can facilitate an increase in corn yield (Morteza *et al.*, 2013).

Azimi *et al.* (2013) reported that the nanosized titanium dioxide particles enhanced the germination rate significantly by 9% compared to the control at 5 ppm in the seeds of wheatgrass, whereas reduction in the germination rate was observed at

80 ppm. The other parameters such as shoot, root, seedling elongation and root biomass were highest at 40 ppm of nano titanium dioxide.

Tarafdar *et al.* (2013) reported that foliar application of nanoscale ZnO on cluster bean (*Cymopsis tetragonoloba* L.) had a significant improvement in plant biomass (27.1%), shoot length (31.5%), root length (66.3%), chlorophyll content (276.2%) and gum content improved by (7.5%) over control.

Kumar *et al.* (2014) studied the effect of nano-fertilizers of gypsum and rock phosphate tagged with urea at the rate of 3 kg/ha on the wheat and found that application of nano-materials and fertilizers significantly increased tillers/m<sup>2</sup>, dry matter accumulation and the days taken to 50 % flowering, physiological maturity and harvest maturity than control and other treatments in comparison.

Foliar application of zinc nano-fertilizer on pearl millet (*Pennisetum americanum* L.) significantly increased shoot length, root length, root area and plant dry biomass (Tarafdar *et al.*, 2014) and on cotton crop increased fresh weight and dry weight have been recorded due to improved physiological processes like chlorophyll content and antioxidant activity (Rezaei and Abbasi, 2014).

Liu & Lal(2014) studied the effect of phosphorus fertilizer on soybean in the form of synthetic apatite nanoparticle and reported that maximum height of the plants(121 cm, 32.6% higher) under nano-hydroxy apatite( nHA )treatment compared to regular P fertilizer (Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>) treatment. However, result also showed that apatite nanoparticles as an alternate P fertilizer to enhance agronomical yield and reduce risks of water eutrophication.

In pearl millet crop increased chlorophyll content, total soluble leaf protein and plant dry biomass were obtained with foliar application of zinc nano-fertilizer (Tarafdar *et al.*, 2014) and in savory plants the contents of chlorophyll, essential oil and phosphorus were increased by nano-zinc application (Vafa *et al.*, 2015).

Studies indicated that exogenous application of some nanoparticles can significantly improve plant growth (Mandeh *et al.*, 2012; Song *et al.*, 2013). Moreover, plant height was more enhanced when nano fertilizer was mixed with the conventional ones, even at a lower application rate (Benzon *et al.*, 2015).

The foliar spray of nTiO<sub>2</sub> increased the total drymatter production of plants by enhancing nitrogen assimilation, photo-reduction activities of photosystem-II and electron transport chain and scavenging of reactive oxygen species (Morteza *et al.*, 2013; Raliya *et al.*, 2015).

Growth parameters like plant height, leaf number and fresh and dry weight of savory plant get increased by nano-zinc application (Vafa *et al.*, 2015).

Benzon *et al.* (2015) stated that full recommended rate of conventional and nano fertilizer (FRR-CF + FRR-NF) enhanced the plant height(3.6%), chlorophyll content(2.72%), no. of reproductive tillers(9.10%), panicles(9.10%) and spikelets(15.42%).

Foliar spraying of nanoformulations of NPK and micronutrients mixture increased the plant height and number of branches in black gram as indicated by Marimuthu and Surendran (2015).

Magda and Hussein(2015) obtained that application of nano phosphorus showed positive effect on corn weight alone as well as in combination with *Beauveria bassiana*.

Hussien *et al.*(2015) reported the interaction effect of nano-fertilizer and drought through some growth stages of cotton plants indicated that application of nano-P at@ 0.5 g/L promoted best nutrients uptake under missing of irrigation at budding stage whereas nano-P fertilizer@ 1.0 g/L depicted the enhanced nutrients uptake under missing of irrigation at flowering stage.

Drostkar *et al.* (2016) stated that foliar application of nano( Zn, Fe and NPK)@2L/plot in chickpea and resulted plant height(28.75 cm) and number of secondary branches (8.62) with nano (NPK+ Zn+ Fe), day to flowering(60.87) with nano Fe, number of primary branches (2.93) with nano NPK foliar application compared to control.

Janmohammadi et al. (2016) found that application of nanosized TiO<sub>2</sub> particles as a foliar spray positively influenced the days to anthesis and chlorophyll content of barley as nTiO<sub>2</sub> can improve structure of chlorophyll and helps better capture of sunlight, facilitates manufacture of pigments, stimulates rubisco activity and also increases photosynthesis.

Soliman *et al.* (2016) explained that baobab plants sprayed with nHA showed a significant increase in plant growth characters (plant height, stem diameter, number of leaves per plant, leaf area, root length, total fresh and dry weights) when compared to control plants. Moreover, significant increase in total chlorophyll, carotenoids concentration, total carbohydrates percentage, vitamin C, macro-elements (N, P and K%), crude protein and total phenols content.

Swetha Kumari *et al.*(2017) explored the effect of bio and nano P fertilizer and reported bio phosphorus proved superior or equivalent to nano phosphorus gave the greatest values for yield and yield parameters.

Kandil *et al.*(2017) investigated on response of some wheat cultivars to nano- , mineral fertilizers and amino acids foliar application and recorded the tallest plant heights (103.64 and 104.20 cm) with mixture of nano- fertilizer + amino acids treatment compared to control for both the season.

Gomma *et al.*(2017) investigated on response to mineral fertilization and nano fertilizers and reported highest values of plant height at harvest( 193.73cm) with application of foliar nano fertilizer as compared to plant height(168.87cm) with application of both mineral fertilizer and foliar nano fertilizer.

Foliar applied nitrogen nano-fertilizer increased the leaf dry weight of peppermint by 165 per cent over control (Rostami *et al.*, 2017).

Upadhyaya *et al.*(2017) recorded the impact of calcium phosphate nano particles on rice plant and resulted the length of roots increased 3.4% and 6% at 10mg/l of calcium phosphate nano particles whereas 1% decrease in root length with 50mg/l of calcium phosphate nano particles showing the toxicity at higher concentration. Also, 8%, 7% increase in root fresh mass and 8%, 18%, 10% increase in shoot fresh mass was observed with 10,20 and 50mg/l concentration.

Rathnayaka *et al.* (2018) studied the influence of urea and nano-nitrogen fertilizers in rice and resulted highest plant height, tiller number, dry weight and yield in plants treated with 100% nano-N fertilizer and the lowest was recorded in no fertilizer treatment.

Sohair *et al.*(2018) reported that significant increase in number of sympodial branches with 50% recommended fertilizer dose of nano NPK fertilizers.

Abdel-Aziz *et al.*(2018) reported that foliar application of nano-chitosan NPK fertilizer decreases the life cycle of wheat plants with 23.5% (130 from 170 DAS).

Choudhary *et al.*(2018) examined for nano phosphorus as managerial input in legume based inter-cropping and resulted significant increase in plant height, dry matter production( $1326.1\text{gm}^{-2}$  and LAI(3.21) in 50% recommended dose of phosphorus with 40% nano phosphorus. Also, 30% more nutrient mobilization and greater nodulation was noticed in rhizosphere in legume with foliar spray of nano phosphorus.

Chiranjeevi *et al.* (2018) investigated for effect of seed treatment with bio-silver nano particles on rice seedlings of cv. NLR 34449 which were dipped in individual 10% silver nano preparation for 10 min and sown with taking two potential antagonistic isolates of *P. fluorescens*( PF-2 and PF-5) and *Trichoderma*(ET-1 and RT-4 ) and reported that maximum shoot length in ET-1 nano (27.4 cm), root length in PF-2 nano (2.6 cm) while S:R ratio in ET-1 spore suspension (11.79) followed by ET-1 nano seed treatment (10.7).

Al-Juthery *et al.*(2018) experimented on wheat taking combination of nano fertilizers and resulted whereas for nano super micro plus(SMP) of 11 nutrients maximum plant height, spike length, Chlorophyll, N, P and K content in leaves (87.77cm, 12.22cm, 58.22 SPAD, 3.17%, 0.66% and 2.88 %, respectively followed by foliar application of tri nano mixed fertilizer of N,P and K. While same trend was observed in the productivity of fertilizers (1936.0, 1581.0 Kg Kg-1) respectively compare with all treatments.

Abdel-Aziz *et al.* (2018) found that nano NPK increased the growth of leaves in wheat, which was obtained by enhanced availability of nutrients by easy penetration of nano formulation of NPK through stomata of leaves via gas uptake.

Erika *et al.* (2019) studied the effect of nano phosphorus and reported that after 7 days of treatment, greater plant height was observed with distilled water(1.6 times) than polymer of nano  $\text{KH}_2\text{PO}_4$  with A gel(1.3 times). However, significant increase

in number of leaves(as 2.0 & 2.3), number of tillers(as 2.8 3.9) and increased instant water use efficiency with nano  $\text{KH}_2\text{PO}_4$  than distilled water.

Jassim *et al.*(2019) conducted an experiment on levels and time of foliar application of nano fertilizer (super micro plus) and resulted superior the level 2g L<sup>-1</sup> nano fertilizer on plant height (125.67 cm), panicle length (25.22 cm), flag leaf area (26.53 cm<sup>2</sup>) and Superior time of adding nano fertilizer in tillering stage on panicle length (24.78 cm) and flag leaf area (25.34 cm<sup>2</sup>)whereas Superior the inter action between levels and times of foliar application in level 2gm.L<sup>-1</sup> in tillering stage on plant height (127.67 cm) and panicle length (26 cm) and flag leaf area (27.11 cm<sup>2</sup>).

Vishekaii *et al.*(2019) examined for the impact of foliar application of boron nano-chelated fertilizer @200 and 300mg L<sup>-1</sup> in olive and recorded the highest number of perfect flower( 4.68), shoot length(12.91 cm) , number of leaves per shoot(25.16) ,chlorophyll content(2.06 mg g<sup>-1</sup> FW) in foliar spray of 300 mg L<sup>-1</sup> of boron nano- chelate compared to control( water spray).

Marzouk *et al.*(2019) experimented on foliar spraying of nano micronutrient fertilizers on snap bean cultivars and resulted enhanced vegetative growth like plant length(45.6 cm), no of leaves(17.3), branches(4.2), pod(21.4), total plant fresh weight(55.4 g), dry matter(15.9%) and total chlorophyll(35.9 SPAD) with foliar application of zinc nano-fertilizer@ 50mgL<sup>-1</sup> compared to control.

Noshad *et al.*(2019) investigated the effect of biogenic AgNPs on seed germination and seedling growth of *Solanum lycopersicum* plants treated with silver nanoparticles (AgNPs)@0.44 mg/L showed significantly enhanced growth parameters including plant height (cm), tomato yield/plant (g), fresh biomass (g), number of shoots/plant, root weight (g), and dry biomass (g) compared to untreated seeds.

Afify *et al.*( 2019)resulted that the treatment of (150+150 ppm) potassium nano foliar application surpassed other treatments in plant height (64.00 cm), shoot fresh weight (185.00 g), shoot dry weight(118.33g), root circumference (30.67 cm), root length (15.00cm) except higher total chlorophyll (62.00 %) with 100ppm potassium nano-fertilizer.

## 2.2 Effect of nano fertilizers on seed yield and its attributes

In groundnut crop pod yield gets increased with the application of nano-scale zinc oxide compared to ZnSO<sub>4</sub> application, on account of nano-scale Zinc is absorbed by plants to larger extent than its chemical form (Prasad *et al.*, 2012).

Nano hydroxyl appetite (nHA) application produced 5.9 g soybean seeds per plant, compared to 4.9 g per plant under regular P treatment, and merely 1.1 and 0.6 g soybean per plant respectively for the controls without P application (Singh *et al.*, 2012).

Prasad *et al.* (2012) reported that pod yield/plant increased by 34% at 1000 ppm concentration of nano zinc oxide (25 nm mean particles size) compared to chelated zinc sulphate (ZnSO<sub>4</sub>). Foliar application of nano-ZnO particles at 15 times lower dose recorded 29.5 percent higher pod yield compared to chelated ZnSO<sub>4</sub>.

Jaberzadeh *et al.* (2013) experimented on titanium treatments on wheat and reported that titanium dioxide nanoparticles @0.02% increased almost all agronomic traits including plant height, ear weight, ear number, seed number, 1000-seed weight, final yield, biomass, harvest index, gluten, and starch contents. He also reported 23.3 percent increase in grain yield with a foliar application of 2 percent nano-Fe over the control.

Armin *et al.* (2014) on wheat crop observed that increasing concentration of nano-fertilizers and time of application had a significant effect on tillers number, seeds per spike, grain yield, biological yield and 1000-grain weight. He reported that foliar application of Fe(4 kg Fe ha<sup>-1</sup> water soluble Fe) had 9.17 % and 5.19 % more grain yield at tillering compared with foliar application of Fe at stem elongation.

Harsini *et al.* (2014) revealed that application of foliar application of nano iron -chelate on wheat cultivars resulted in significant increase in spike number, 1000-grain weight, grains number per spike, biological yield, grain yield and harvest index in wheat crop than control and other treatments.

Tarafdar *et al.* (2014) reported that zinc nano-fertilizer applied as foliar spray on pearl millet (*Pennisetum americanum* L.) significantly increased the grain yield by 37.7 %.

Delfani et al. (2014) suggested that spraying of  $0.5 \text{ g L}^{-1}$  nano Fe to the black-eyed pea improved the number of pods per plant, weight of 1000 seeds, yield, and chlorophyll content compared to common Fe.

Liu & Lal(2014) reported that increase in maximum seed yield per plant (20.4%), biomass productions were enhanced by 18.2% (above-ground) and 41.2% (below-ground) with nano-hydroxy apatite(nHA) treatment compared to regular P fertilizer ( $\text{Ca}(\text{H}_2\text{PO}_4)_2$ ).

Singh *et al.*(2015) reported that seed oil content increased with increased concentration of nano ZnS in sunflower. Also, application of nano ZnS 500 ppm at 55 days after sowing significantly increased the seed yield of sunflower.

Benzon *et al.*(2015), reported that application of full recommended rate of conventional with nano fertilizer enhanced the panicle weight (17.4%), total grain weight(unpolished-17.5%, polished-20.7%), total shoot dry weight (15.3%) and harvest index(2.9%).

Bakhtiari *et al.* (2015) studied the effect of foliar application and time of iron nanoparticles (nano-Fe) on wheat and reported that nano-Fe (0.04 %) had the highest values of spike weight (614.88 g), 1000 grain weight (36.10 g), biological yield (8830 kg/ha), grain yield (3639.5 kg/ha) and protein content (16.01 %) whereas the lowest values were recorded in the control.

Kumara *et al.* (2016) experimented on the foliar application of nano calcite@100 ppm in rice cultivar and reported positive effect on yield components of rice including number of panicles /plant (9.17), number of filled grains /panicle (137) and 1000 grain weight (26.42 g).

Drostkar *et al.* (2016) stated that foliar application of nano( Zn, Fe and NPK)@2L/plot in chickpea and resulted highest seed yield ( $137.3 \text{ g/ m}^2$ ), number of seeds per plants (25.45), seed weight (25.32g) , seed protein content(20.36%) by nano (Fe + Zn) foliar application, biological yield ( $303.2\text{g/m}^2$ ) with nano NPK, number of pods per plant (22.88) and HI(45.9%) with Zn foliar application compared to control.

Abdel-Aziz *et al.* (2016) found that use of foliar spray of 10% nano chitosan-NPK (nano10) have better result in clay sandy than clay soil as shoot length(72.80,68.33cm), spike length(20.90,18.00cm), plant height(93.20,86.33cm),

main spike weight(4.17,3.01g), no. of spikelets/main spike(19.20,17.33 cm), 100 kernel weight(7.01,6.02g),grain yield/plant(7.63,6.12g), straw yield(1.59,1.51g) and harvest index(4.80 to 4.05) while reverse trend was seen in yield/plant(11.70 & 11.90).

In pomegranate, fruit yield and number of fruits per tree get increased with the foliar spraying of nano-scale Zinc and Boron fertilizers (34 mg B tree<sup>-1</sup> or 636 mg Zn tree<sup>-1</sup>, respectively) (Davarpanah *et al.*, 2016).

Nano-scale zinc oxide particle at 40 ppm treatment was associated with increased rice grain yield and its components in mid tillering and PI stages (Ghasemi *et al.*, 2017).

The highest spike length (11.85 and 12.35 cm), spikes number/m<sup>2</sup> (312.00 and 316.66 ), highest values for spikelets number/spike (18.72 and 18.39 spikelets), grains number/spike (56.33 and 54.83 grains), 1000- kernel weight (53.04 and 54.45 g), highest values for grain yield (2620.76 and 2677.39 kg/fed.), straw yield (3408.76 and 3402.55 kg/fed.) and biological yield (6029.51 and 6079.94 kg/fed.) for both the season were recorded in wheat using mixture of nano- fertilizer + amino acids treatment compared to control(Kandil *et al.*,2017).

Gomaa *et al.*(2017) reported highest values of ear length(17.44, 18.42), no. of rows/ear(15.10, 15.11), no. of grains/row(40.33, 42.95), no. of grains/ear(709.28, 754.8) and 100-grain weight(47.33g, 46.52g), biological yield(18.76 ton/ha, 17.93ton/ha), grain yield(8.68ton/ha, 8.35ton/ha) and straw yield(10.08ton/ha, 9.58ton/ha) with application of mineral fertilizer in soil with foliar application of nano fertilizer followed by only foliar application of nano fertilizer.

Sohair *et al.* (2018) depicted 10.79% increase in seed cotton yield due to increase in boll weight at 3 times compared to 2 times of application and higher yield, i.e, 11.85% and 8.34% in foliar nano fertilizers than soil application.

With respect to phosphorus management practice, maximum grain yield (1162 kg/ha) and straw yield(5148 kg/ha) of pigeon pea, black gram and maize were recorded with 50% RDP + 40 ppm nano-P followed by 100% RDP and 40 ppm nano-P(Choudhary *et al.*, 2018).

Hagab *et al.*(2018) reported that application of nano-zeolite phosphorus resulted in the highest values of yield components including pod (1.89 ton fed-1), straw (3.48 ton fed-1), seeds crop (1.46 ton fed-1) and oil content (53.2 %).

Al-Juthery *et al.*(2018) experimented on wheat and resulted higher biological yield (13.364Mg ha-1) and grain yield of (5.996Mg ha-1) with spraying of NSMP, thousand grain weight, highest value was also observed in (N+P+K) T5 (47.25g)and NSMP T6 treatment(47.88g), harvest index is concerned the highest value was observed in NSMP T6 applied treatment, followed by nano mixture fertilizer (N+P+K)and (N+P) while lowest (P+K) (44.96, 43.18, 37.65%).

Jassim *et al.*(2019) experimented on levels and time of foliar application of nano fertilizer (super micro plus) and resulted superior the level 2g L<sup>-1</sup> nano fertilizer on number of seeds per panicle (123.33) and number of panicle per m<sup>2</sup> (323.8) and percent of fertility (16.67 %) and weight of 1000 seed (20.31 gm) and grain yield (540 gm.m<sup>-2</sup>) whereas Superior the inter action between levels and times of foliar application in level 2gm.L<sup>-1</sup> in tillering stage on number of seeds per panicle (125.67) and number of panicle per m<sup>2</sup> (329) and percent of fertility (15.67 %) and weight of 1000 seed (20.53 gm) and grain yield (547 gm.m<sup>-2</sup>).

Vishekaii *et al.*(2019) examined for the impact of foliar application of boron nano-chelated fertilizer @200 and 300mg L<sup>-1</sup> on yield attributes in olive and recorded the highest fruit set(3.13%), fruit weight(41.02 g), yield(61.01 kg/tree) and yield efficiency(0.26 kg/cm<sup>2</sup>) in foliar spray of 300 mg L<sup>-1</sup> of boron nano-chelate compared to control( water spray).

Marzouk *et al.*(2019) reported that pod length(11.1cm), pod diameter(0.72cm), pod fresh weight(5.9g), pod dry weight(2.3g) and total yield(5 ton/feddan) with foliar application of Zinc nano-fertilizer@ 50mgL<sup>-1</sup> compared to control.

Afify *et al.*( 2019) resulted that the treatment of (150+150 ppm) potassium nano foliar application showed significant enhancement in no. of branches/ plant(10.33 ), no. of pods/ plant(54.33), pods yield/ plant (68.67 g), no. of seeds/ plant(75.67), seed yield/plant (45.33g), pod yield(2746.67 kg/fed) seed yield

(1813.33kg/fed), oil yield (983.57 kg/fed), shilling (40.52 %) with 100ppm and oil (54.97 %) with (100 + 100)ppm potassium nano-fertilizer.

### 2.3 Effect of nano fertilizers on seed quality parameters

Nair *et al.* (2010) investigated the effects of both SWCNTs and MWCNTs on the germination of rice seeds and observed the enhanced germination of seeds in the presence of nanotubes.

Rathinam *et al.* (2011) studied the effect of nano silica on maize crop and resulted the nano silica increases seed germination (2–11 %), water use efficiency (up to 53 %), and total chlorophyll content (13–17 %) of maize crop.

Mazumdar and Ahmed (2011) noticed the adverse effect of silver nanoparticles @ 1000  $\mu\text{g ml}^{-1}$ , 1200  $\mu\text{g ml}^{-1}$  and 1600  $\mu\text{g ml}^{-1}$  on seed germination, root and shoot length of paddy, green gram and mustard, respectively.

Salama (2012) studied the effects of silver nanoparticles on plant growth parameters such as shoot and root lengths, leaf surface area, chlorophyll, carbohydrate and protein contents of common bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.) with five levels of silver nanoparticles (20, 40, 60, 80 and 100 ppm) and reported that increase in concentration of silver nanoparticles from 20 to 60 ppm has increased shoot lengths (19 and 12%), root lengths (21 and 18%), leaf surface area (22 and 26%), chlorophyll (49 and 33%), carbohydrate contents (57 and 62%) and protein contents (30 and 24%) of common bean and corn plants.

Rangaraj *et al.* (2012) revealed an increase in germination percentage (95.5 %) and dry weight ( $6.52 \pm 0.2$ ) in seeds exposed to nano-SiO<sub>2</sub> in maize than in those exposed to bulk sources.

Sandeep *et al.* (2012) achieved maximum germination (97 %) with 25 ppm of Au NP treatment on 3rd day after inoculation compared to control (80 %). This indicated that Gold-nanoparticle treatment reduces the time required for seed germination.

Sani (2012) experimented on the effect of different concentrations (0, 0.02, 0.03 and 0.04 percentage) of TiO<sub>2</sub> nanoparticles on seed quality parameters of maize

and reported highest germination percentage, seedling vigour, seedling length and seedling dry weight @0.03% TiO<sub>2</sub> nanoparticle.

Hassan *et al.* (2012) reported the lowest and the highest mean germination time (0.89 vs. 1.35 days) were obtained in 10 ppm concentration of nanosized TiO<sub>2</sub> and control treatments, respectively in wheat. In addition, shoot and seedling lengths at 2 and 10 ppm concentrations of nanosized TiO<sub>2</sub> were higher than those of the untreated control and bulk TiO<sub>2</sub> at 2 and 10 ppm concentrations. Employing nanosized TiO<sub>2</sub> in suitable concentration could promote the seed germination of wheat in comparison to bulk TiO<sub>2</sub> but in high concentrations had inhibitory or any effect on wheat. The lowest shoot length was achieved at 100 ppm nanosized TiO<sub>2</sub> and 2 ppm bulk TiO<sub>2</sub> treatments.

Prasad *et al.* (2012) suggested that ZnO nanoparticles at a concentration of 1000 ppm improved the germination (99 %), root growth (11.81 cm), shoot growth (8.71 cm), pod dry weight (5.39 g) and pod yield (3763 kg ha<sup>-1</sup>) in groundnut.

Tapan *et al.* (2013) reported that maximum growth including seed germination 95-100%, root (5.4%) and shoot (8%) length was found at 40 ppm SiO<sub>2</sub> nano particles and 5 ppm Mo nanoparticles for rice seedlings. Also rice seedlings showed 42% increase in the root biomass and 19% increase in shoot biomass over control.

Yugandhar and Savithamma (2013) found that the biologically synthesized calcium carbonate nanoparticles were more effective in accelerating seed germination, seedling vigor index, root and shoot length, fresh and dry weight and relative water content of mung (*Vigna mungo*).

Tarafdar *et al.* (2013) reported the ZnO nanoparticle biosynthesis and its effect on phosphorous-mobilizing enzyme secretion and gum contents in cluster bean. The ZnO nanoparticles were foliar sprayed at 10 ppm concentration on leaf of 14 days old plants. A significant improvement in plant biomass (27.1 %), shoot length (31.5 %), root length (66.3 %), root area (73.5 %), chlorophyll content (276.2 %), total soluble leaf protein (27.1 %), rhizospheric microbial population (11–14 %), acid phosphatase (73.5 %), alkaline phosphatase (48.7 %) and phytase (72.4 %) activity in cluster bean rhizosphere was observed over control in 6 week old plants. The seed gum content

improved by 7.5 % after maturity which indicated that ZnO in nano form may contribute more in industrial and medical applications besides agricultural sector.

Shyla *et al.* (2014) reported the effect of metal nanoparticles (ZnO, Ag, TiO<sub>2</sub>,) on germination of groundnut seeds. The highest maximum germination percentage was promoted by ZnO nanoparticle (67 %), which was 2 percent and 3 per cent higher than the Ag (65%) and TiO<sub>2</sub> NPs (63%), respectively.

Ushahra *et al.* (2014) reported that biogenic nanoparticles promotes seed germination(80%), speed of germination( $2.02\pm 0.26$ ), coefficient of germination( $22.73\pm 2.5$ ), mean germination time( $0.8\pm 0.45$ ), shoot length( $3.5\pm 0.28$ ) and root length( $4.2\pm 0.47$ ), fresh weight( $0.238\pm 0.028$ ), dry matter( $0.021\pm 0.0028$ ) and vigour index( $616\pm 2.78$ ) in *Eruca sativa* (garden rocket) var. RTM 314 over control by overcoming the detrimental effects of reactive oxygen species (ROS) and improving the antioxidative defense system.

Acharya *et al.* (2014) studied about nanoprimering on onion and found out result of germination, growth and quality of onion seed and found germination percentage to be 47% and 19% higher in AuNPs treatment at 6 and 21 DAS respectively as compared to controls.

Benzon *et al.*(2015) resulted enhanced total phenolic content by 51.67% with half recommended rate of nano fertilizer compared to full recommended rate of conventional fertilizer + full recommended rate of nano fertilizer.

Mir *et al.*(2015) studied the effect of nano and biological fertilizers on carbohydrate and chlorophyll content of forage sorghum and stated that the highest chlorophyll a (1.59 mg/g), chlorophyll b (5.31 mg/g), carotenoid (2.24 mg/g) and carbohydrate (3.24 mg/g) were achieved from combine biofertilizers (azetobarvar 1+ phosphorbarvar 2) + chelated nano fertilizers (Fe+k) treatments application.

Mahakham *et al.*(2016) studied the effect of gold nano particles(GNPs) in maize and postulated that priming with 5ppm GNPs showed best effects on promoting emergence percentage (83%) compared to unprimed controls(43%) and hydroprimed groups (56%). Seed priming both at 5 & 10 ppm GNPs enhanced seedling vigor index by three times over control.

Anandaraj and Natarajan (2017) studied on seed quality enhancement of onion seeds which are highly prone to deterioration in storage (aged seeds) and concluded that enhancement in seed quality parameters like- highest germination of 72%, maximum shoot length (7.5 cm), higher root length (6.4cm), highest vigour Index(998) with ZnO NPs treated seeds @ 1000mg kg<sup>-1</sup> and also reported that nanoparticles treatment did not influence the seed physiology immediately after treatment but has significant effect after six months of aged seed compared to control (60%, 6.0, 5.4 and 692) respectively.

Mahakham *et al.*(2017) reported increase in germination percentage (averaged 73.3% and 93.3%), enhancement in expression of aquaporin genes, especially PIP2, increase in imbibition, activity of CAT after 24 hrs of germination(71% and 61%) and after 24 hrs of imbibitions, increase in O<sub>2</sub> content by ~42% and 33%, increase in  $\alpha$ -amylase activity of seedlings(2.6 and 2.5 folds) with seeds nanoprimed with AgNPs10mg/l and AgNPs20mg/l compared to control and almost (1.3 and 1.2 times) greater than hydropriming. Similar trend was observed in root dehydrogenase activity within crement upto (~2.3 to 2.5-fold) in AgNPs10mg/l and AgNPs20mg/l nanopriming treatments over unprimed seedlings.

Anandaraj and Natarajan (2017) studied the effect of nanoparticles for seed quality enhancement in onion and reported that onion seeds when dry dressed with the synthesized nanoparticles- Zinc oxide (ZnO), Silver oxide(AgO), Copper oxide (CuO) and Titanium dioxide (TiO<sub>2</sub> each at 750, 1000, 1250 and 1500 mg kg<sup>-1</sup>, the dose of 1000 mg kg<sup>-1</sup> outperformed in enhancing the germination (72%), shoot length (7.5 cm) root length (6.4) and thereby the vigour index (998).

Al-Juthery *et al.*(2018) experimented on wheat and reported protein content of the wheat grains protein (13.69%) was obtained in nano super micro plus fertilizer compared to tri nano (N+P+K) treatment (13.33%).

Sohair *et al.*(2018) reported maximum seed index(9.11g), maximum lint weight(40.54%) in three times foliar application at 50% nano RFD compared to minimum seed index(8.14g) and lint weight(36.78%) in two times soil application at 12.5% nano-RFD.

Chiranjeevi *et al.* (2018) investigated for effect of seed treatment with bio-silver nano particles on rice seedlings of cv. NLR 34449 and reported that maximum germination % in ET-1 nano (100%) while a reverse trend in vigour index as maximum in ET-1 spore suspension treated seeds (3114) followed by ET-1 nano (3090).

Vishekaii *et al.*(2019) examined for the impact of foliar application of boron nano-chelated fertilizer @200 and 300mg L<sup>-1</sup> on oil content, and quality attributes in olive and reported highest oil yield(32.82kg/tree) ,total phenolic content(57.26 mg/kg oil) and carbohydrate contents(53.43 and 61.50mg g<sup>-1</sup> for two season) compared to control(water spray).

The present investigation entitled “Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.)” was conducted during kharif season of 2019 on rice cv. Mandakini at Central Research Farm, Regional Research and Technology Transfer Station, OUAT, Bhubaneswar. The materials used and methodologies followed are described in this chapter.

The crop was sown on 19<sup>th</sup> July 2019 using the variety Mandakini for this experiment purpose. The plots were treated with different doses of fertilizer, farm yard manure. Seed treatment with Vitavax power@ 3g/kg seed before sowing. The treatment plots are treated with foliar application of nano phosphorus @ 40ml/litre. The vegetative and reproductive growth behavior of rice in response to foliar application of nano phosphorus were recorded in the field, then seed quality attributes were evaluated in the laboratory after the crop was harvested. The details of material and methods followed in the experiment are as follows:

### **3.1 Experimental Site**

#### **3.1.1 Field Experiment:**

The experiment was conducted at Central Research Farm, Regional Research and Technology Transfer Station, OUAT, Bhubaneswar between latitude 20.2961°N and longitude 85.8245°E with an average altitude of 45 m (148 ft) mean sea level. This particular location comes under the East & South Eastern coastal Plain Zone of agro-climatic zone of Odisha.

#### **3.1.2 Laboratory Experiment**

Laboratory evaluation on seed quality attributes were done in Seed Physiology Laboratory, Dept. Of Seed Science and Technology, College of Agriculture, OUAT, Bhubaneswar and Dr. G. V. Chalam Seed Testing & Research Laboratory, AICRP on Seed Technology Research, NSP(Crops), OUAT, Bhubaneswar

### **3.2 Soil of the experimental field**

Composite soil samples from the top 0-15 cm were collected from the experimental site before sowing and they were analyzed for “N” by Alkaline Permanganate method (Subbaiah and Asija, 1956), “P” by Bray’s Extractant method

(Bray's and Kurtz, 1945), "K" by flame photometry method (Jackson, 1973) & pH by pH meter (Piper, 1996), sand, silt & clay by International Pipette method (Piper, 1996), Electrical Conductivity (ds/m) by Conductivity Bridge method (Jackson, 1967) and Organic Carbon (%) by Wet Oxidation method. The results of soil analysis are presented in table 1.

**Table 1. Initial nutrient status of soil of the experimental plot.**

Sl. No.	Parameter	Value
1.	Sand (%)	72.8
	Silt (%)	12.6
	Clay (%)	14.6
	Textural class	Loamy sand
2.	Bulk density( g/cc)	1.58
3.	pH	5.38
4.	E.C (dS/m)	0.004
5.	Organic carbon (g /kg)	4.35
6.	Available N (kg/ha)	223
7.	Available P (kg/ha)	12
8.	Available K (kg/ha)	68

### 3.3 Climate condition

The weekly meteorological data recorded at the meteorological observatory, OUAT, Bhubaneswar, Odisha viz. mean maximum and minimum temperature, bright sunshine hours, relative humidity I & II and rainfall, for the crop growing period of 2019 have been presented in the following table. 2

**Table 2. Meteorological data during the period of study (July to December, 2019)**

<b>Period</b>	<b>Standard week</b>	<b>Mean maximum temperature (°C)</b>	<b>Mean minimum temperature (°C)</b>	<b>Morning relative humidity (%)</b>	<b>Evening relative humidity (%)</b>	<b>Rainfall (mm)</b>
July	27(1-7)	30.9	25.9	94	85.1	94
July	28(8-14)	34	25.9	90.7	70.3	90.7
July	29(13-21)	35.2	26.3	90.9	62.7	90.9
July	30(22-28)	31.9	25.6	94.6	76.6	94.6
July	31(29-4)	31.2	26	92.9	76.9	48.9
Aug	32(5-11)	32.6	26	93.1	74.4	101.5
Aug	33(12-18)	32.3	26	95	79.7	73.1
Aug	34(19-25)	32.5	26	96.4	80.6	87.3
Aug	35(26-1)	32	26.2	94.1	76.9	9.8
Sept	36(2-8)	32.3	26.1	95.4	77	108.7
Sept	37(9-15)	32.1	26.2	93.6	76.9	40.3
Sept	38(16-22)	33.6	26	92.4	72.4	23.2
Sept	39(23-29)	29.9	24.4	95.6	88.6	234.3
Sept	40(30-6)	33.7	24.9	92.1	68.3	5.2
Oct	41(7-13)	32.5	24.4	95.9	71.7	52.1
Oct	42(14-20)	32.4	23.8	92.9	63.3	2
Oct	43(21-27)	32.4	24	96.1	80.7	253.3
Oct	44(28-3)	31.8	23.4	94.7	59.9	0
Nov	45(4-10)	30.3	21.6	92.8	54.2	5.2
Nov	46(11-17)	30.9	19.6	92.3	51.3	0
Nov	47(18-24)	30	18.1	94	51.2	0
Nov	48(25-1)	29.7	18.5	95.7	57.9	0
Dec	49(2-8)	29.1	16.9	91.6	53	0
Dec	50(9-15)	30.4	18.1	93	58.7	0
Dec	51(16-22)	27.3	16.4	92.8	60	0
Dec	52(23-29)	26.1	13.2	86.8	50.5	1.3
<b>Mean</b>		<b>34.42</b>	<b>23.43</b>	<b>93.21</b>	<b>68.41</b>	

### **3.4 Seed crop details**

#### **3.4.1 Test crop –**

Rice cv. Mandakini was taken for this experiment purpose. The germination percentage was 86% as tested in the laboratory.

#### **3.4.2 Treatment details**

**T<sub>1</sub>**: Control

**T<sub>2</sub>**: 100% STD (75:37.5:37.5 NPK Kg/ha)

**T<sub>3</sub>**: 100% STD+spray of water (500 litre/ha) at 14 DAT

**T<sub>4</sub>**: 100% STD+spray of nano P (40ml/litre) at 14 DAT

**T<sub>5</sub>**: 100% STD+ 2 spray of nano P (40ml/litre) at 14 and 28 DAT

**T<sub>6</sub>**: 100% NK & 75% P of STD + 2 spray of nano P (40ml/litre) at 14 and 28 DAT

**T<sub>7</sub>**: 100% NK & 50% P of STD + 2 spray of nano P (40ml/litre) at 14 and 28 DAT

#### **3.4.3 Experimental design**

Experimental design- Randomized Block Design

No. of Replications- 03

No. of Treatments- 07

Plot size- 4.9 m x 4.5 m

#### **3.4.4 Seed material**

Rice cv. Mandakini was selected for the research purpose and some of the varietal characters were depicted below.

- i. Parentage of Mandakini rice variety is Ghanteswari x IR 27069 and released in 2010 by Department of Plant Breeding and Genetics, College of Agriculture, OUAT, Bhubaneswar.
- ii. Maturity period- (105-110) days.
- iii. Medium slender grain, dull red kernel, straw colour hull
- iv. Resistance to blast, sheath blight & moderately resistance to sheath rot, sheath blight.
- v. Resistance to insects like gall midge, leaf folder, whorl maggot & moderately resistance to rice tungro virus.

### **3.5 Raising of Seed Crop**

The rice crop was sown in nursery area on 19<sup>th</sup> July 2019 in the morning hours by using the variety Mandakini. The seedlings were transplanted to the main field on 18<sup>th</sup> August 2019 using 10 days old seedlings in the plot of size (4.9×4.5) m<sup>2</sup> area. A spacing of (20×15)cm was maintained in the plot. Fertilizers were given to the experimental plots according to the treatment details given. Sources of fertilizer used in this experiment purpose was Urea, DAP and MOP (murate of potash). The soil application of ¼ N, P, ½ K fertilizer was done as basal dose, ½ N and ½K was top dressed and remaining ¼ N was given at the time of flowering. FYM was applied to the soil before sowing of the crop. Pendimethalin was applied to main plot to control weeds @ 1litre/acre (250ml) as pre-emergent herbicide on 20<sup>th</sup> August 2019. All the required agronomic and plant protection practices were adopted at proper time for the benefit of the seed crop and to protect it from diseases and pest. Irrigation was done at regular interval when required. Different field parameters were recorded on field. Harvesting of the crop was done at harvestable maturity stage. 10 plants from each treatment and control plot was taken with proper labeling and dried under sun. Then the panicles were separated from the plants and placed in labeled containers for drying. The dried pods were threshed by hand and seeds were collected after sieving in cloth bags. Then the seeds were dried under sun to lower down the moisture content and stored in cloth bags with proper labeling in ambient condition. The post-harvest observations were recorded in the laboratory.

### **3.6 Recording of Observation**

10 plants were taken randomly from treatment and control plots from each of 3 replications and were tagged separately to record the following observations.

#### **3.6.1 Growth Parameters:**

Several plant growth parameters were recorded from each plot of the experiment and the following observations were recorded during the examination.

##### **3.6.1.1 Days to 50% flowering**

Days to completion of 50% flowering in each plot of the replications occupied by rice was recorded and expressed in days after sowing.

### 3.6.1.2 Days to maturity

Plants were observed for maturity. The day on which all plants matured is considered as complete maturity. The number of days taken from the date of sowing to maturity was calculated and expressed in number as days taken to maturity.

### 3.6.1.3 Chlorophyll content

Leaf samples from the 10 selected plants were taken from each treatment and control of each replication at 40 DAS and the total chlorophyll content estimated by as per the method given by Arnon (1949). Leaf samples of 100 mg weight from each treatment was taken. Acetone solution of 80% concentration was prepared. The leaf samples were chopped and put in test tubes along with 10 ml of 80% acetone solution and volume was makeup to 25ml. These were kept in dark for 24 hours. After that the reading were taken by spectrophotometer at 663nm and 645nm, taking 80% acetone as a blank. Mean chlorophyll content of each plot was calculated and expressed as mg/g FW. The total chlorophyll content was calculated using the following formula.

$$\text{Chl a} = \frac{[(12.7 \times A_{663}) - (2.69 \times A_{645})]}{1000 \times w} \times v$$

$$\text{Chl b} = \frac{[(22.9 \times A_{645}) - (4.68 \times A_{663})]}{1000 \times w} \times v$$

$$\text{Total chl.} = \frac{[(8.02 \times A_{663}) + (20.2 \times A_{645})]}{1000 \times w} \times v$$

Where,

W= weight of leaf sample(100mg)

V= volume of 80% acetone( 25ml)

A= absorbance

### 3.6.1.4 Total number of tillers at maximum tillering stage/ hill

At maximum tillering stage, 5 number of hills were taken and total number of tillers in each hill was counted and recorded.

### **3.6.1.5 Plant height**

The main stem height was measured from the base of the plant to the tip of the longest leaf and average height of 10 sampled plants from each treatment and control of each replication and expressed in centimeter.

### **3.6.2 Yield and yield components**

#### **3.6.2.1 Effective tillers/hill**

5 number of hills were taken randomly at maturity stage and the number of effective tillers/hill were recorded.

#### **3.6.2.2 Panicle length**

The length obtained from the 10 selected panicles from the sampled plants from each treatment and control of each replication was noted and the average length of panicle was calculated and expressed in centimeter.

#### **3.6.2.3 Number of spikelets per panicle**

The total number of spikelets obtained from the 10 selected panicles after threshing from the sampled plants from each treatment and control of each replication was counted and the average number of spikelets per panicle was calculated.

#### **3.6.2.4 Filled grain/panicle**

5 number of panicles were taken randomly from each treatment and control of each replication and total number of filled grain per panicle was observed and recorded in percentage.

#### **3.6.2.5 Unfilled grain/panicle**

5 number of panicles were taken randomly from each treatment and control of each replication and number of unfilled grains per panicle were observed, then number of the same were recorded in percentage.

### **3.6.2.6 1000- seed weight(g)**

The seeds collected from the sampled plants of each treatment and control of each replication were counted after drying and their weight was recorded by using an analytical balance and expressed in gram.

### **3.6.2.7 Seed yield/hill(g)**

The weight of seeds obtained from all the panicles harvested from the ten selected hills after proper drying under sun. Then the seed yield per hill was computed and expressed in g/hill.

### **3.6.2.8 Seed yield/hectare(q)**

Seed yield per hectare under each treatment was computed from recorded seed yield per plot data and was expressed in q/ha.

### **3.6.2.9 Harvest Index(%)**

It was calculated by following formula and recorded in percentage.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

## **3.6.3 Seed quality parameters**

### **3.6.3.1 Seed moisture content**

Moisture content of rice seeds was determined by Air Oven Method (ISTA, 1985) taking duplicate samples. The seed material was grinded in a seed grinder into a fine powder. About 5 g of finely ground seed material was taken separately from each treatment in a pre-weighed (M1) moisture box and the weight was recorded (M2). The moisture boxes were then placed in a hot air oven maintained at 103°C for 17 hours. After that the moisture boxes were taken out and allowed to cool to room temperature in a desiccator. The final weight (M3) was recorded. The moisture content was calculated using the following formula and expressed as percentage on wet weight basis.

$$\text{Seed moisture content (\%)} = \frac{\text{Loss in weight}}{\text{Initial weight of seed}} \times 100 = \frac{M2-M3}{M2-M1} \times 100$$

Where,

M1 = Weight of empty moisture box + its lid

M2 = Weight of moisture box + lid + seed before drying

M3 = Weight of moisture box + lid + seed after drying

### **3.6.3.2 Germination percentage**

The germination percentage of freshly harvested seeds (100 seeds) of each treatment and replication was calculated by using Between Paper method (Anon, 1999) and expressed in percentage. Germination percentage was calculated as:

$$\text{Seed germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds put for germination}} \times 100$$

### **3.6.3.3 Field emergence**

One hundred seeds produced under each treatment were sown in rows of 5 m length with a spacing of 20 cm x 10 cm in a leveled field. Water was sprinkled at intervals to maintain proper soil moisture condition. After 14 days the number of seedlings emerged from soil were counted and the field emergence percentage was calculated.

### **3.6.3.4 Mean seedling length(cm)**

Ten no. of normal seedlings were selected randomly in each replication from all the treatments after taking the final count in germination test. The seedling length was measured from the tip of the primary leaf to the root tip with the help of a scale and mean seedling length was expressed in centimetre.

### **3.6.3.5 Root length (cm)**

The length of the roots was measured on ten randomly selected seedlings from the 14th day of germination test and the average was expressed in centimeter.

### **3.6.3.6 Shoot length (cm)**

The shoots length (collar region to tip of topmost leaf) was measured on the same ten random seedlings whose root length was measured earlier and was expressed in centimeter.

### **3.6.3.7 Mean seedling dry weight**

The ten normal seedlings used for seedling length measurement were used for measurement of seedling dry weight. After removing the remnant portion of the endosperm, only the plumule and radicle were put in butter paper packet and kept in hot air oven at  $110 \pm 1^{\circ}\text{C}$  for 24 hours. Weight of the oven-dried seedlings was taken in an electronic balance and their mean value expressed in gram.

### **3.6.3.8 Seedling vigour indices**

After germination test and measurement of seedling length and seedling dry weight, seed vigour indices I & II were calculated using the formulae given by AbdulBaki and Anderson (1973).

Seedling Vigour Index-I = Germination (%) x Mean seedling length (cm)

Seedling Vigour Index-II = Germination (%) x Mean seedling dry weight (g)

### **3.6.3.9 Conductivity of seed leachate**

Conductivity of seed leachate was measured by adopting the procedure of Sahoo *et al.*, (2006). Eight grams of rice seeds were weighed accurately with the help of an electronic balance and were kept separately in beaker of 100 ml capacity. To the beaker 40 ml of distilled water was added. The beaker was kept in an incubator at  $30^{\circ}\text{C}$  for 6 hrs. Then the beaker was brought out of the incubator and water was decanted to another beaker and the conductivity of seed leachate was measured by the help of conductivity meter and the value was expressed as deci Siemens per metre (dS/m).

### **3.6.3.10 Accelerated ageing test**

The storability of rice seeds produced under different treatments were studied by accelerated ageing method. Here hundred seeds from each treatment of the three replications were exposed to  $45^{\circ}\text{C}$  and 95% relative humidity for 96 hours in an ageing chamber. The treated seeds were brought out of the ageing chamber and kept

under laboratory condition for germination test by using “Between Paper” method as per ISTA rule (Anon, 1999). Then, the germination percentage, root length, shoot length, seed vigour index I & II were assessed and recorded.

#### **3.6.3.10.1 Seed germination after accelerated ageing**

Seed of each treatment was kept in accelerated ageing chamber and subjected to accelerated ageing conditions such as high temperature (45<sup>0</sup>C) and high humidity (95%) for a period of 96 hours. After that the standard germination test was test as in 3.6.3.2 and the normal seedling count taken after seven days. The germination percentage after accelerated ageing was calculated as:

$$\text{Seed germination after AA(\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds put for germination}} \times 100$$

#### **3.6.3.10.2 Seedling length and dry weight after accelerated ageing**

Ten normal seedlings of the aged seeds were selected randomly in each replication from all the treatments after taking the final count in germination test. The seedling length was measured from the tip of the primary leaf to the root tip with the help of a scale and mean seedling length was expressed in centimetre. Weight of the ten random oven-dried seedlings was taken in an electronic balance and their mean value expressed in milligram.

#### **3.6.3.10.3 Seed vigour indices after accelerated ageing**

From the germination and seedling growth data, seed vigour indices were calculated as per the following formulae suggested by Abdul-Baki and Anderson (1973):

$$\text{Seedling vigour index-I} = \text{Germination (\%)} \times \text{Mean seedling length (cm)}$$

$$\text{Seedling vigour index-II} = \text{Germination (\%)} \times \text{Mean seedling dry weight (g)}$$

### **3.7 Statistical analysis**

The planned observation data recorded in various field and laboratory examinations were subjected to statistical analysis following the principles and procedures which were outlined by Panse and Sukhatme (1978).

The results of the investigation on “Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.)” which was conducted in Kharif season of 2019 at Central Farm, Regional Research and Technology Transfer Station, Coastal Zone OUAT, Bhubaneswar, Odisha have been presented in this chapter.

The field experiment was done in randomized block design with seven treatments in three replication. The treatments were: Control (T<sub>1</sub>), 100% STD(75:37.5:37.5 NPK, Kg/ha) (T<sub>2</sub>), 100% STD + spray of water (500L/ha) at 14 DAT (T<sub>3</sub>), 100% STD + spray of nano phosphorus (40 ml/litre) at 14 DAT (T<sub>4</sub>), 100% STD + 2 sprays of nano phosphorus(40 ml/litre) at 14 and 28 DAT (T<sub>5</sub>), 100% NK & 75% P of STD +2 sprays of nano phosphorus (40 ml/litre) at 14 and 28 DAT (T<sub>6</sub>), 100% NK & 50% P of STD + 2 sprays of nano phosphorus(40 ml/litre) at 14 and 28 DAT (T<sub>7</sub>).

In this investigation, the parameters relevant to the plant growth, seed yield and yield components and different seed quality attributes including storability have been studied in seed crop of rice taking Mandakini variety. Data pertaining to the observations from the present investigation recorded on plant growth parameters, yield & yield components and seed quality parameters were tested statistically and described with the help of relevant tables, graphs and figures along with detailed description of the data.

#### **4.1 Effect of nano phosphorus on plant growth parameters**

##### **Days to 50% flowering**

The ANOVA indicated presence of significant variation among the different treatments for the study on effect of foliar nano phosphorus on days to 50% flowering. The mean value of the treatments ranged from 83.33 days (T<sub>4</sub>, T<sub>5</sub>, T<sub>6</sub>) to 86 days (T<sub>1</sub>) with an overall mean of 84.05 days (Table 3). The treatments T<sub>3</sub> (84.33 days) & T<sub>2</sub>, T<sub>7</sub> (84 days) were at par with each other. Earlier flowering was recorded in T<sub>4</sub>, T<sub>5</sub> and T<sub>6</sub> whereas control had taken significantly higher days to 50% flowering(86 days). There was a difference of nearly 1 or 2 days among the treatments.

### Days to maturity

The analysis of variance indicated presence of significant variation among the various treatments for days to maturity. The mean value of the treatments varied from 107.3 days (T<sub>5</sub>) to 111 days (T<sub>1</sub>) with an overall mean of 109.3 days (Table 3). The treatment T<sub>7</sub> (110.7 days) was at par with control (111 days). Earlier maturity were recorded in T<sub>5</sub> (107.3 days) followed by T<sub>6</sub> (108.0) and T<sub>4</sub>(108.3) whereas control took significantly higher days to maturity, i.e, 111 days. There was almost 2 to 3 days difference in the treatments for this character.

**Table 3. Effect of foliar application of nano phosphorus on days to 50% flowering and days to maturity in rice cv. Mandakini.**

Treatments	Days to 50% flowering	Days to maturity
T <sub>1</sub> : Control	86.00	111.0
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	84.00	109.7
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	84.33	110.0
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	83.33	108.3
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	83.33	107.3
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	83.33	108.0
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	84.00	110.7
Mean	84.05	109.3
SEm (±)	0.480	0.466
CD (5%)	1.479	1.436

### Plant height (cm)

Significant differences among the different treatments was observed for plant height. The value of the treatments ranged from 119.5 cm (T<sub>5</sub>) to 112 cm (T<sub>1</sub>) with an overall mean of 115.89 cm (Table 4.).The highest plant height was recorded in the treatment T<sub>5</sub> (119.5 cm) with 100% STD + 2 sprays of nano P followed by T<sub>2</sub> (118.2 cm) with 100% STD which were at par with each other and showing 6.7% and 5.5% taller plants than control (112 cm). The lowest plant height was recorded in control(112 cm). All treatments except T<sub>7</sub> (113.9 cm) were at par with the treatment T<sub>2</sub> (118.2 cm).

### Total tillers/hill

The analysis of variance for total tillers/hill showed significant variation among different treatments. Treatment with the highest value was T<sub>5</sub>(8.87) and the lowest was T<sub>1</sub>(6.67) with an overall mean of 8.05(Table 4). All treatments registered significantly higher values than control (6.67). All treatments except T<sub>6</sub> (7.60)and control (6.67) were at par with the treatment T<sub>5</sub> with 100% STD and 2 sprays of nano P (8.87).

**Table 4.Effect of foliar application of nano phosphorus on plant height, total tillers/hills and Total chlorophyll content(mg/g FW) in rice cv. Mandakini.**

Treatments	Plant height (cm)	Total tillers/hill	Total chlorophyll content (mg/g FW)
T <sub>1</sub> : Control	112.0	6.67	2.61
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	118.2	8.27	2.91
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	116.4	7.87	3.23
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	115.9	8.53	3.23
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at14 & 28 DAT	119.5	8.87	3.61
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at14 & 28 DAT	115.3	7.60	3.53
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at14 & 28 DAT	113.9	8.53	3.22
Mean	115.89	8.05	3.19
SEm (±)	1.170	0.331	0.188
CD (5%)	3.608	1.021	0.580

### **Total chlorophyll content(mg/g FW)**

The analysis of variance for total chlorophyll content indicated presence of significant variation among the different treatments involving foliar spray of nano-phosphorus. The mean value of the treatments ranged from 2.61 mg/g FW (T<sub>1</sub>) to 3.61 mg/g FW (T<sub>5</sub>) with an overall mean of 3.19 mg/gFW (Table 4). All the treatments except 100% STD(T<sub>2</sub>) and control were shown significantly higher values for this trait. Numerically the highest chlorophyll content 3.61 mg/g FW was found in 100% STD with 2 foliar sprays of nano-P(T<sub>5</sub>) closely followed by T<sub>6</sub>(3.53 mg/g FW) with 100% NK & 75% P of STD + 2 sprays of nano P whereas the lowest total chlorophyll content was recorded in T<sub>1</sub> (2.61 mg/g FW).

### **4.2 Effect of nano phosphorus on seed yield and yield attributes**

#### **Effective tillers/hill**

Significant variation was found among different treatments for effective tillers/hill. The value of treatments ranged from 5.80 (T<sub>1</sub>) to 8.07(T<sub>5</sub>) with an overall mean of 7.03(Table 4). All treatments registered significantly higher values than control (5.80). All treatments except T<sub>1</sub>(5.80) and T<sub>5</sub>(8.07) were statistically at par with the treatment T<sub>2</sub> with 100% STD. The treatment comprising 100% STD with 2 spray of nano-P (T<sub>5</sub>) showed highest number of effective tillers which is 31.1% higher than the control (5.80).

#### **Panicle length(cm)**

The analysis of variance for panicle length(cm) showed significant difference among different treatments. The mean value of the treatments ranged from 20.87cm (T<sub>1</sub>) to 24.73cm(T<sub>3</sub>) with an overall mean of 23.77 cm (Table 5). The highest panicle length was observed in the treatment T<sub>5</sub> (24.73 cm) followed by T<sub>3</sub>(24.47cm), T<sub>6</sub>(24.33cm),T<sub>2</sub>(24.27cm) whereas lower panicle length was recorded in treatment T<sub>1</sub>(20.87cm).All treatments registered significantly higher values than control ( 20.87 cm).All treatments except control were statistically at par with the treatment T<sub>2</sub> with 100% STD.

#### **No of spikelets/panicle**

There was significant difference between treatments for this trait. The mean values of the treatments ranged from 121.0 (T<sub>1</sub>) to 133.4 (T<sub>5</sub>) with an overall mean of 128.5 (Table 5). Treatments T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> had shown significantly higher values over

control (121.0). All treatments were statistically at par with the treatment T<sub>2</sub> applied with 100% STD. Numerically more spikelets were found in combination treatments with different doses of STD and 2 foliar application of nano phosphorus. The lowest spikelets/panicle of 121.0 was recorded in the control treatment.

**Table 5. Effect of foliar application of nano phosphorus on effective tillers/hill, panicle length (cm) and no of spikelets/ panicle in rice cv. Mandakini.**

Treatments	Panicle length (cm)	No of spikelets/ panicle	Effective tillers/ hill
T <sub>1</sub> : Control	20.87	121.0	5.80
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	24.27	126.1	7.00
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	24.47	128.0	7.03
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	23.80	128.6	7.07
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	24.73	133.4	8.07
T <sub>6</sub> : 100% NK & 75% P of STD+ 2 sprays of nano P at 14 & 28 DAT	24.33	132.8	7.27
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	23.93	129.5	7.00
Mean	23.77	128.5	7.03
SEm (±)	0.607	2.784	0.293
CD (5%)	1.87	8.5	0.903

#### **Filled grains/panicle (%)**

The analysis of variance for this trait showed significant variation among different treatments. The mean value of the treatments ranged from 87.18(T<sub>1</sub>) to 91.63(T<sub>5</sub>) with an overall mean of 89.86 (Table 6). The maximum filled grains/panicle was recorded in treatment T<sub>5</sub> (91.63) followed by other treatments which was 5.1% higher than control (87.18) whereas lowest filled grains/panicle was recorded in the treatment T<sub>1</sub>(87.18). All treatments recorded significantly higher grains/panicle than control. The treatment T<sub>2</sub> comprising 100% STD (90.44%) was statistically at par with the remaining treatments except control.

### Unfilled grains/panicle (%)

The analysis of variance for this character indicated significant variation among the different treatments for the study of their effect of nano phosphorus on percentage of unfilled grains per panicle. The mean value of the treatments ranged from 8.37 (T<sub>5</sub>) to 11.15 (control) with an overall mean of 9.28 (Table 6). All treatments showed significantly lower values than control (11.15). The treatment T<sub>5</sub> (8.37) indicated lowest percentage of unfilled grains per panicle which was 24.93% lower than control (11.15) followed by T<sub>7</sub> (8.70) whereas the highest unfilled grains/panicle was recorded in treatment T<sub>1</sub> (11.15). The treatment T<sub>2</sub> comprising 100% STD (9.22%) was also statistically at par with the remaining treatments having variable dosage of STD with nano-P except control.

**Table 6. Effect of foliar application of nano phosphorus on filled grains/ panicle (%) and unfilled grains/panicle (%) in rice cv. Mandakini.**

Treatments	Filled grains/panicle (%)	Unfilled grains/panicle (%)
T <sub>1</sub> : Control	87.18	11.15
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	90.44	9.22
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	89.52	9.15
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	90.76	9.24
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	91.63	8.37
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	90.52	9.14
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	88.96	8.70
Mean	89.86	9.28
SEm (±)	0.556	0.511
CD (5%)	1.71	1.57

### **1000-seed weight (g)**

A significant variation was observed among the various treatments for 1000-seed weight, i.e, test weight. The mean value of the treatments ranged from 22.97g (T<sub>1</sub>) to 25.13g (T<sub>5</sub>) with an overall mean of 24.54g (Table 7). All treatments had significantly higher test weight than control with 22.97 g. The treatment T<sub>5</sub> (25.13) indicated maximum 1000-seed weight with 9.4 % higher than control followed by other treatments whereas the lowest 1000-seed weight was recorded in treatment T<sub>1</sub> (24.97). The treatment T<sub>2</sub> (24.70 g) comprising 100% STD was also statistically at par with the remaining treatments having variable dosage of STD with nano-P except control.

### **Seed yield/hill (g)**

Seed yield per hill exhibited significant variation among the different treatments as revealed by the ANOVA for this trait. It ranged from 10.92 g (T<sub>1</sub>) to 15.65 g (T<sub>5</sub>) with an overall mean of 13.93 g among different treatments (Table 7). All treatments showed significantly higher values than control (10.92 g). The maximum seed yield/hill was recorded in treatments T<sub>5</sub> (15.65 g) followed by T<sub>4</sub> (15.20 g) which had 43.31% and 39.19% higher seed yield/hill than control (10.92 g). The lowest seed yield/hill was recorded in treatment T<sub>1</sub> (10.92 g). Like test weight and some others, the treatment T<sub>2</sub> (14.28 g) comprising 100% STD was also at par with the remaining treatments including T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> except control.

### **Seed yield/ha (q)**

The most important economic character, seed yield/ha registered significant differences among the different treatments. Its mean values for various treatments varied from 17.24 q/ha in T<sub>1</sub>(control) to 26.23q/ha in T<sub>5</sub>, with an overall mean of 23.92 q/ha (Table 7). All treatments had significantly higher values than control (17.24 q/ha). The treatment T<sub>5</sub> (26.23q/ha) recorded the highest seed yield closely followed by T<sub>4</sub> (25.82 q/ha) which had 52.14% and 49.77% higher yield than control (17.24 q/ha). Like test weight and seed yield/hill, the treatment T<sub>2</sub> (24.94q/ha) applied with 100% STD was also at par with the remaining treatments including T<sub>5</sub> (26.23 q/ha) and T<sub>6</sub> (24.72 q/ha), but significantly higher than T<sub>7</sub> (50% STD for P + 2 sprays of nano-P at 14 and 28 DAT) which yielded 23.26 q/ha.

**Table 7. Effect of foliar application of nano phosphorus on 1000 seed weight, seed yield/hill, seed yield/ha and HI in rice cv. Mandakini.**

Treatments	1000 seed weight (g)	Seed yield/hill (g)	Seed yield/ha (q)	HI (%)
T <sub>1</sub> : Control	22.97	10.92	17.24	45.36
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	24.70	14.28	24.94	52.11
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	24.23	14.52	25.21	51.23
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	24.77	15.20	25.82	54.30
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	25.13	15.65	26.23	54.49
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	25.03	14.21	24.72	54.01
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	24.97	12.76	23.26	49.65
Mean	24.54	13.93	23.92	51.59
SEm (±)	0.286	0.558	0.429	1.222
CD (5%)	0.88	1.72	1.32	3.77

### Harvest Index (%)

The ANOVA showed significant variation among the different treatments in this study of effect of foliar spray of nano-phosphorus on HI%. The treatments had a range of 45.36% (T<sub>1</sub>) to 54.49% (T<sub>5</sub>) with an overall mean of 51.59% (Table 7). The highest HI was recorded in the treatment T<sub>5</sub> (54.49%) with 100% STD and 2 times spray of nano-p followed by T<sub>4</sub> (54.30%) and T<sub>6</sub> (54.01%) showing 20.13%, 19.71% and 19.07% higher HI% than control (45.36%), whereas the lowest was in control (45.36%). All treatments had significantly higher values than control. The treatment T<sub>2</sub> with 100% STD (52.11%) was at par with the remaining treatments including T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> except control.

### 4.3 Effect of nano phosphorus on seed quality parameters

#### Seed moisture content (%)

The analysis of variance for seed moisture content indicated non-significant variation among various treatments. The treatments means varied from 11.14% (T<sub>7</sub>) to 12.07% (T<sub>5</sub>) with an overall mean of 11.57% (Table 8). Numerically higher percentage of seed moisture content was indicated in the treatment T<sub>5</sub> (12.03%) followed by T<sub>3</sub> (11.82%), T<sub>6</sub> (11.73%) T<sub>4</sub> (11.70%), whereas lowest seed moisture content was recorded in the treatment T<sub>7</sub> (11.14 %).

**Table 8. Effect of foliar application of nano phosphorus on seed moisture (%) in rice cv. Mandakini.**

Treatments	Seed moisture (%)
T <sub>1</sub> : Control	11.21
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	11.34
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	11.82
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	11.70
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	12.07
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	11.73
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	11.14
Mean	11.57
SEm (±)	0.410
CD (5%)	NS

### **Electrical conductivity of seed leachate (dS/m)**

Electrical conductivity (EC) of seed leachate is an accurate indicator of seed vigour. Strong and negative relationship between EC and seed vigour have been reported by many workers in many crops (Hamdi and Elemery, 1996).

The ANOVA for EC showed significant variation among the different treatments for the study of their effect of nano phosphorus on electrical conductivity of seed leachate. The mean value of the treatments ranged from 0.050 dS/m (T<sub>7</sub>) to 0.073 dS/m (T<sub>1</sub>) with an overall mean of 0.06 dS/m (Table 9). All treatments except T<sub>2</sub> and T<sub>3</sub> had significantly lower values than T<sub>1</sub> (0.073 dS/m). The treatment T<sub>2</sub> (0.067 dS/m) was at par with T<sub>3</sub> (0.062 dS/m) while it was significantly lower than T<sub>4</sub> to T<sub>7</sub>, indicating better vigour of these treatments compared to T<sub>2</sub> and T<sub>3</sub>. The minimum electrical conductivity of seed leachate was recorded in treatments T<sub>4</sub>&T<sub>7</sub>(0.051 and 0.050 dS/m).

### **Seed germination (%)**

Germination percentage is the standard physiological parameter which is commonly used to assess the planting value of seeds. In the present study, germination tests were conducted by between paper (BP) method using fresh seeds after breaking dormancy.

The analysis of variance for germination percentage indicated significant variation among the different treatments. The mean value of the treatments ranged from 82.00% (T<sub>1</sub>) to 93.00% (T<sub>5</sub>) with an overall mean of 89.49% (Table 9). All treatments showed significantly higher values over control (82.00%). The maximum seed germination was recorded in the treatment T<sub>5</sub> (93.00 %) which was 13.41 % higher than control (82.00 %). All treatments including T<sub>6</sub> and T<sub>7</sub> except in control had significantly higher values than T<sub>2</sub> (89.07%) with 100% STD.

**Table 9. Effect of foliar application of nano phosphorus on electrical conductivity of seed leachate (dS/m) and germination (%) in rice cv. Mandakini.**

<b>Treatments</b>	<b>Electrical conductivity of seed leachate (dS/m)</b>	<b>Germination (%)</b>
T <sub>1</sub> : Control	0.073	82.00 (9.06)
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	0.067	89.07(9.44)
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	0.062	90.67(9.52)
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	0.051	91.33(9.55)
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	0.053	93.00(9.64)
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	0.053	90.33(9.50)
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	0.050	90.00(9.49)
Mean	0.06	89.49
SEm (±)	0.004	0.077
CD (5%)	0.013	0.23

NB:- Figures in the parentheses indicate square root transformed values.

### **First count (%)**

First count (%) also registered significant variation among the different treatments in the study of the effect of nano phosphorus on this trait. Its mean values ranged from 67.33 % (T<sub>1</sub>) to 73.67 % (T<sub>4</sub>) with an overall mean of 71.05% (Table 10). The maximum first count was recorded in the treatment T<sub>4</sub> (73.67 %) which was 7.23 % higher than control (67.33 %) whereas the lowest first count value was recorded in treatment T<sub>1</sub> (55.15 %). All treatments except T<sub>7</sub> (70.33) showed significantly higher values over control. All treatments including T<sub>6</sub> and T<sub>7</sub> except control were at par with T<sub>2</sub>(71.00%).

### Field emergence (%)

Field emergence gives a realistic picture about assessment of stand establishment potential of seed lots. The condition of field where seeds germinate and seedlings emerge out from the soil are less favorable than the condition during germination tests under laboratory, hence low seed vigour seeds perish under field condition.

The analysis of variance for this character indicated significant variation among the different treatments for the study of their effect of nano phosphorus on field emergence. The mean value of the treatments ranged from 79.00 % (T<sub>1</sub>) to 90.67 % (T<sub>5</sub>) with an overall mean of 86.72% (Table 10). All treatments had shown significantly higher values over T<sub>1</sub> (88.9 %) for this trait. The maximum field emergence was recorded in the treatments T<sub>5</sub> (90.67%) followed by T<sub>4</sub> (88.67) and T<sub>3</sub> (88.33) showing 14.77%, 12.24% and 11.81%, higher field emergence than control respectively. The lowest field emergence was recorded in treatment T<sub>1</sub> (79.00 %). Most of the treatments including T<sub>6</sub> and T<sub>7</sub> receiving nano-P sprays except control were significantly superior to T<sub>2</sub> (93.1%).

**Table 10. Effect of foliar application of nano phosphorus on first count and field emergence in rice cv. Mandakini.**

Treatments	First count (%)	Field emergence (%)
T <sub>1</sub> : Control	67.33 (55.15)	79.00(8.89)
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	71.00 (57.42)	86.73(9.31)
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	70.67 (57.52)	88.33(9.40)
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	73.67 (59.14)	88.67(9.41)
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	73.33 (58.92)	90.67(9.52)
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	71.00 (57.42)	87.33(9.35)
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	70.33 (57.02)	86.33(9.29)
Mean	71.05	86.72
SEm (±)	0.672	0.089
CD (5%)	2.071	0.275

NB:- Figures in the parentheses indicate arcsin transformed values for First count and square root transformed values for Field emergence.

### **Seedling shoot length (cm)**

Shoot length is an important parameter which reflects early seedling growth during germination of crop seeds. In the present investigation, this parameter was measured on the final day of germination count, i.e, final count.

The analysis of variance for seedling shoot length indicated presence of significant variation among various treatments. The mean value of the treatments varied from 7.77cm (T<sub>1</sub>) to 8.95 cm (T<sub>6</sub>) with an overall mean of 8.53 cm (Table 11). All treatments except T<sub>7</sub> had shown significantly higher values over T<sub>1</sub> (88.9 %) for this trait. The highest shoot length was indicated in the treatment T<sub>6</sub> (8.95 cm) followed by T<sub>4</sub> (8.93 cm) and T<sub>2</sub> (8.87 cm), whereas lowest shoot length was recorded in the treatment control (7.77 cm). All treatments including T<sub>6</sub> and T<sub>7</sub> except control were at par with T<sub>2</sub> (8.87 cm).

### **Seedling root length (cm)**

Measurement of root length is a part of the procedure to assess early seedling growth of germinated seeds. Root length was measured on the day of final count.

The analysis of variance for this character indicated significant variation among the different treatments. The mean values of the treatments ranged from 12.90 cm (T<sub>1</sub>) to 15.20 cm (T<sub>5</sub>) with an overall mean of 14.36 cm (Table 11). All treatments except T<sub>7</sub> had significantly higher values for this trait as compared to T<sub>1</sub> (12.90cm). The maximum root length was recorded in the treatment T<sub>5</sub> (15.20 cm) which was 17.83 % higher than the control, followed by T<sub>2</sub> (14.97 cm) and T<sub>3</sub> (14.69 cm) showing 16.05 % and 13.88 %, higher root length than control, respectively,. The lowest seedling root length was recorded in treatment T<sub>1</sub> (12.90 cm). All treatments including T<sub>6</sub> and T<sub>7</sub> except control and T<sub>7</sub> were statistically at par with T<sub>2</sub> (14.97 cm).

### **Seedling length (cm)**

The ANOVA for this character indicated significant variation among the different treatments. The mean value of the treatments ranged from 20.67 cm (T<sub>1</sub>) to 23.94 cm (T<sub>5</sub>) with an overall mean of 22.90 cm (Table 11). All treatments except T<sub>7</sub> had significantly higher values for this trait as compared to T<sub>1</sub> (20.67 cm). The maximum seedling length was recorded in the treatments T<sub>5</sub> (23.94 cm) followed by T<sub>2</sub> (23.83 cm), T<sub>4</sub>(23.50 cm) and T<sub>6</sub>(23.47 cm) which were at par with each other and

showed 16.72 %, 15.29 %, 13.69 % and 13.55% respectively, higher seedling length than control. The lowest seedling length was recorded in treatment T<sub>1</sub> (20.67 cm). All treatments except control and T<sub>7</sub> were statistically at par with T<sub>2</sub> (23.83 cm).

**Table 11. Effect of foliar application of nano phosphorus on seedling shoot, root length and seedling length in rice cv. Mandakini.**

Treatments	Seedling shoot length (cm)	Seedling root length (cm)	Seedling length (cm)
T <sub>1</sub> : Control	7.77	12.90	20.67
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	8.87	14.97	23.83
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	8.65	14.69	23.33
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	8.93	14.57	23.50
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	8.74	15.20	23.94
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	8.95	14.52	23.47
T <sub>7</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	7.82	13.71	21.52
Mean	8.53	14.36	22.90
SEm (±)	0.225	0.346	0.391
CD (5%)	0.69	1.06	1.21

### Seedling dry weight (mg)

Measurement of seedling dry weight of germinating seeds provides information about growth pattern of seedling and translocation of food reserve to the root as well as shoot growth behavior during germination. The seedling dry weight was measured after drying the seedlings obtained on the day of final count during germination test.

The analysis of variance for seedling dry weight indicated presence of significant variation among various treatments. The mean value of the treatments varied from 63.9 mg (T<sub>3</sub>) to 75.5 mg (T<sub>5</sub>) with an overall mean of 70.90 mg (Table 12). All treatments had significantly higher values for this trait as compared to T<sub>1</sub> (63.9 mg). The maximum seedling dry weight was indicated in the treatment T<sub>5</sub> (75.5 mg) followed by T<sub>4</sub> (74.2 mg) which were at par with each other showing 18.15% and 16.12% higher weight than control whereas lowest value for seedling dry weight was recorded in T<sub>1</sub>(63.9 mg).The treatment T<sub>2</sub> (72.3 mg) was statistically at par with rest treatments including T<sub>5</sub> to T<sub>7</sub>.

### **Seed vigour**

The stand establishment potential of a seed lot is predicted more precisely basing on seed vigour than on the basis of laboratory germination percentage. The performance of crop varieties also largely depend upon seed vigour (Mathews, 1993). Therefore any study involving seed production and quality assessment, due emphasis is given on seed vigour. The common parameter used to represent seed vigour is the seed vigour index (SVI) which is measured by integrating two other physiological quality parameters germination percent and seedlings length (SVI-I) or dry weight (SVI-II).

### **Seedling vigour index-I**

Seedling vigour index-I indicated significant differences among the different treatments applied with STD and nano phosphorus. The mean value of the treatments ranged from 1694.3 (T<sub>1</sub>) to 2226.6 (T<sub>5</sub>) with an overall mean of 2051.6 (Table 12). All treatments had shown significantly higher values compared with T<sub>1</sub> (1694.3) for this trait. The maximum SVI-I was recorded in the treatment T<sub>5</sub> (2226.6) which showed 31.42% increase over control whereas the lowest seedling vigour index-I was recorded in treatment T<sub>1</sub> (1694.3).The treatment T<sub>2</sub> (2123.1) was statistically at par with rest treatments except T<sub>7</sub> (1936.9).

### **Seedling vigour index-II**

The analysis of variance for seedling vigour index-II indicated presence of significant variation among various treatments. The mean values of the treatments

varied from 5.24(T<sub>1</sub>) to 7.02 (T<sub>5</sub>) with an overall mean of 6.35(Table 12). The highest SVI-II was indicated in the treatment T<sub>5</sub> (7.02) followed by T<sub>4</sub>(6.77), T<sub>3</sub> (6.46) and T<sub>2</sub> (6.44) indicating 33.97%, 29.2%, 23.28% and 22.9% higher value over control, whereas lowest seedling vigour index-II was recorded in the treatment T<sub>1</sub> (5.24).All treatments showed significantly higher values compared with T<sub>1</sub> (5.24).The treatment T<sub>2</sub> (6.44) was statistically at par with remaining treatments except T<sub>5</sub> (7.02) and control.

**Table 12.Effect of foliar application of nano phosphorus on seedling dry weight and seed vigour indices in rice cv. Mandakini.**

<b>Treatments</b>	<b>Seedling dry wt (mg)</b>	<b>SVI –I</b>	<b>SVI –II</b>
T <sub>1</sub> : Control	63.9	1,694.3	5.24
T <sub>2</sub> : 100% STD (75:37.5:37.5 NPK kg/ha)	72.3	2,123.1	6.44
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	71.3	2,114.3	6.46
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	74.2	2,145.9	6.77
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at14& 28 DAT	75.5	2,226.6	7.02
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at14& 28 DAT	70.0	2,120.0	6.32
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at14& 28 DAT	69.1	1,936.9	6.22
Mean	70.90	2,051.6	6.35
SEm (±)	1.418	41.408	0.143
CD (5%)	4.4	127.6	0.44

### **Seed germination (%) after accelerated ageing**

The accelerated ageing (AA) vigour test provides valuable information on both seed storability and field seedling emergence potentials. The AA stress exposes

seeds for relatively short period to high to high temperature (41°C) and RH (about 95%) followed by a germination test. This combination of raised seed water content and high temperature causes rapid seed ageing. High vigour seeds are more tolerant to these stressful conditions and produce a higher percentage of normal seedlings.

The ANOVA for seed germination after accelerated ageing indicated significant variation among the different treatments. The mean value of the treatments ranged from 74.67 % (T<sub>1</sub>) to 87.67 % (T<sub>5</sub>) with an overall mean of 84.14 % (Table 13). All treatments showed significantly higher values compared with control (74.67 %). The maximum seed germination was recorded in the treatment T<sub>5</sub> (87.67 %) which was 17.40 % higher than control, whereas the lowest seed germination was recorded in control (74.67 %). The treatment T<sub>2</sub> (85.00%) was statistically at par with remaining treatments except control for seed germination.

**Table 13. Effect of foliar application of nano phosphorus on germination (%) and field emergence(%) after accelerated ageing in rice cv. Mandakini.**

Treatments	Germination (%)	Field emergence (%)
T <sub>1</sub> : Control	74.67 (8.64)	73.67 (8.58)
T <sub>2</sub> : STD (75:37.5:37.5 NPK kg/ha)	85.00 (9.22)	83.33 (9.13)
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	85.33 (9.24)	85.00 (9.22)
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	86.33 (9.29)	85.67 (9.25)
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at14 & 28 DAT	87.67 (9.36)	87.33 (9.34)
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at14 & 28 DAT	85.00 (9.22)	84.00 (9.17)
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at14 & 28 DAT	85.00 (9.22)	82.00 (9.06)
Mean	84.14	83.00
SEm (±)	0.068	0.052
CD (5%)	0.21	0.16

NB:- Figures in the parentheses indicate square root transformed values.

### **Field emergence (%)**

The ANOVA for seedling field emergence after accelerated ageing indicated significant variation among the different treatments. The mean value of the treatments ranged from 73.67 % (T<sub>1</sub>) to 87.33 % (T<sub>5</sub>) with an overall mean of 83.00 % (Table 13). All treatments showed significantly higher emergence compared with control (73.67 %). The maximum emergence was recorded in the treatment T<sub>5</sub> (87.33 %) which was 18.54 % higher than control, whereas the lowest seed germination was recorded in control (73.67 %). The treatment T<sub>2</sub> (83.33%) was statistically at par with remaining treatments except T<sub>5</sub> (87.33%) and control for seedling field emergence.

### **Seedling vigour index-I (SVI-I) after accelerated ageing**

The analysis of variance for SVI-I indicated significant variation among the different treatments. The mean values of the treatments ranged from 1298.5(T<sub>1</sub>) to 1880.2 (T<sub>5</sub>) with an overall mean of 1695.3 (Table 14). All treatments registered significantly higher values compared with control (1298.5). The maximum SV-I was recorded in the treatment T<sub>5</sub> (1880.2) which was 44.8% higher than control followed by T<sub>4</sub> (1792.9), T<sub>2</sub> (1777.1) and T<sub>3</sub> (1768.9) which were at par with each other and showing 33.22%, 36.86% and 36.23% respectively, higher SV-I than control, whereas the lowest seedling vigour index-I was recorded in treatment T<sub>1</sub> (1298.5). The treatment T<sub>2</sub> (1777.1) was statistically at par with remaining treatments except T<sub>7</sub> (1594.6) and control.

### **Seedling vigour index-II after accelerated ageing**

The analysis of variance for seedling vigour index-II after accelerated ageing indicated presence of significant variation among various treatments. The treatment means varied from 4.30(T<sub>1</sub>) to 6.20(T<sub>5</sub>) with an overall mean of 5.58(Table 14). All treatments except T<sub>7</sub> (4.30) registered significantly higher SVI-II compared with control (1298.5). SVI-II was highest in the treatment T<sub>5</sub> (6.20) followed by T<sub>4</sub>(6.04) and T<sub>2</sub> (5.73), whereas lowest seedling vigour index-II was recorded in the treatment control (4.30). The treatment T<sub>2</sub> (6.44) applied with 100% STD was statistically at par with remaining treatments except T<sub>5</sub> (7.02), T<sub>7</sub>(4.30) and control, where it was significantly higher than T<sub>7</sub>receiving 50% STD for P + 2 spays of nano-P.

**Table 14. Effect of foliar application of nano phosphorus on seed vigour indices after accelerated ageing in rice cv. Mandakini.**

<b>Treatments</b>	<b>SVI -I</b>	<b>SVI –II</b>
T <sub>1</sub> : Control	1,298.5	4.30
T <sub>2</sub> : STD (75:37.5:37.5 NPK kg/ha)	1,777.1	5.73
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	1,768.9	5.72
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	1,792.9	6.04
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at 14 & 28 DAT	1,880.2	6.20
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at 14 & 28 DAT	1,755.0	5.57
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at 14 & 28 DAT	1,594.6	4.30
Mean	1,695.3	5.58
SEm (±)	54.749	0.137
CD (5%)	168.8	0.42

#### **Reduction in germination percentage and SV I & II after accelerated ageing**

The significant reduction in germination percentage and seedling vigour indices were noticed after accelerated ageing as listed in the Table 15. Relatively lower reduction in germination (4.07%), SVI-I (15.6%) and SVI-II (11.%) were noticed in treatment T<sub>5</sub> with 100% STD and 2 times foliar spray of nano phosphorus indicating more tolerance to stress and better storability of seeds. Maximum reduction in all three parameters like-germination (7.33%), SVI-I (23.4%) and SVI-II (17.9%) were recorded in control. Treatment with 100% STD only showed lower reduction compared to T<sub>6</sub> & T<sub>7</sub>.

**Table 15.Reduction (%) in germination and seed vigour indices after accelerated ageing in rice cv. Mandakini.**

<b>Treatments</b>	<b>Germination (%)</b>	<b>SVI -I</b>	<b>SVI – II</b>
T <sub>1</sub> : Control	7.33	23.4	17.9
T <sub>2</sub> : STD (75:37.5:37.5 NPK kg/ha)	5.33	16.3	11.0
T <sub>3</sub> : 100% STD+ spray of water (500 litres/ha) at 14 DAT	5.33	16.3	11.5
T <sub>4</sub> : 100% STD+ spray of nano P (40ml/litre) at 14 DAT	5.00	16.5	10.7
T <sub>5</sub> : 100% STD+ 2 sprays of nano P at14& 28 DAT	4.07	15.6	11.7
T <sub>6</sub> : 100% NK & 75% P of STD + 2 sprays of nano P at14& 28 DAT	5.33	17.2	11.9
T <sub>7</sub> : 100% NK & 50% P of STD + 2 sprays of nano P at14& 28 DAT	5.00	17.7	12.2

The results of the present investigation on “Effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.)” conducted during *kharif* season of 2019 at Central Research Farm, Regional Research and Technology Transfer Station, Coastal Zone, OUAT, Bhubaneswar using rice cv. Mandakini. The effect of foliar application of nano-P with variable dosage of STD on rice have been discussed in this chapter.

### **5.1 Effect of foliar application of nano phosphorus on plant growth parameters**

Any treatment showing better plant growth and yield components are expected to produce higher yield. In the following paragraphs, observations recorded on various plant growth parameters in response to the foliar application of nano-P @40 ml/litre at 14 DAT or 14 and 28 DAT along with soil application of different dosage of STD are briefly discussed.

In the present study, days to 50% flowering and days to maturity indicated presence of significant variation among the different treatments. All treatments except 100% STD + 2 sprays of nano-P at 14 and 28 DAP were statistically at par with control (86 days) and the treatment 100% STD took similar time to reach 50% flowering as the treatment with 50% or 75% STD for P + 2 sprays of nano-P. Combination of STD with foliar nano-P resulted earlier days to 50% flowering i.e. 83.33 in treatment T4, T5 and T6. There was a difference of nearly 1 or 2 days among the treatments. This result is similar to the findings obtained by Drostkar *et al.* (2016) and Kumar *et al.* (2014) in related studies.

Determination of harvestable maturity is crucial to maintain seed quality, since over-maturity affects the sowing quality of seeds. Harvestable maturity is achieved when the seed moisture content is reduced to safe limits to take up further post-harvest operations. In this study, days to maturity ranged from 107.3-111 days with significant variation among the various treatments. Significantly earlier maturity was recorded in 100% STD + 1 or 2 sprays of nano-P and 75% STD for P + 2 sprays of nano-P compared to 100% STD indicating the earlier maturity by nano-P application. This earliness may be due to reduction in reproductive period of the seed crop. There

was almost 2 to 3 days difference in the treatments for this character. This result is in accordance with the findings of Kumar *et al.* (2014) and Abdel-Aziz *et al.* (2018).

All treatments except 50% STD for P + 2 sprays of nano-P had similar plant height compared to conventional 100% STD application, suggesting that reducing the STD to 50% level obviously reduced the tallness, while up to 75% STD there was little effect while highest plant height was obtained using 100% STD along with 2 sprays of nano-P at 14 and 28 days, i.e., 119.5 cm suggesting nano-P can either provide nutrients for the plant or aid in the transport or absorption of available nutrients resulting in better crop growth. The study by Benzon *et al.* (2015), Rathnayaka *et al.* (2018), Erika *et al.* (2019), Choudhary *et al.* (2018), Gomaa *et al.* (2017), Vafa *et al.* (2015), Jassim *et al.* (2019) and Kandil *et al.* (2017) had revealed similar findings.

Total tillers/hill showed significant variation among different treatments. Treatment with 100% STD with 2 sprays of nano-P (T<sub>5</sub>) showed the highest value (8.87) and the lowest was T<sub>1</sub> (6.67). All treatments registered significantly higher values than control (5.67). All treatments except 75% STD for P + 2 sprays of nano-P and control had similar effect as the treatment T<sub>5</sub> (8.87). Miranda-Villagómez *et al.* (2019) also reported that nano phosphorus fertilizer stimulates growth rate and photosynthetic activity and improves P status in rice. Also another studies by Rathnayaka *et al.* (2018), Erika *et al.* (2019) and Kumar *et al.* (2014) had registered similar results.

Total chlorophyll content of leaves noted at 28 DAT indicated presence of significant variation among the different treatments with values ranged from 2.61 mg/g FW (T<sub>1</sub>) to 3.61 mg/g FW (T<sub>5</sub>) with an overall mean of 3.19 mg/g FW. This chlorophyll content can be attributed to the actively growing stages of rice plant. According to Taiz and Zeiger (2006), leaves begin their development as sink organs and a transition from sink to source status occurs later in development resulting in reversal transport. Nanofertilizers may have affected their processes through its transportation capabilities in terms of penetration and movement within the plant systems. Using this nano materials, increment in total chlorophyll content was also resulted by the studies of Vishekaii *et al.* (2019), Tarafdar *et al.* (2013), Kumar *et al.* (2014) and Al-Juthery *et al.* (2018).

## 5.2 Effect of foliar application of nano phosphorus on seed yield and its attributes

Seed yield is determinant of three of its components such as effective tillers/hill, no. of filled grains/panicle and 1000-seed weight. In rice, increase in value of one or combination of these characters results in enhancement of seed yield.

In the present study, the agronomic characters such as effective tillers/hill, filled grains/panicle, unfilled grains/panicle, 1000-seed weight, seed yield/hill, seed yield/ha and HI were affected significantly in all treatments when compared to control, which indicated that the application of nutrients as 100% STD or variable doses of STD for P in conjunction with 1 or 2 sprays of nano-P could positively influence these traits. These traits are discussed as follows.

Effective tillers per hill showed significant increment in number using nano phosphorus ranged from 5.80 in control to 8.07 in 100% STD+2 sprays of nano-P (T<sub>5</sub>) which was 31.1% higher than control. Benzon *et al.* (2015) also reported that full dose STD in combination with nano fertilizer caused 9.10% increase in number of effective tiller per hill over full STD.

Significant increase in number of spikelets per panicle and panicle length was observed in rice with the combination of 100% STD and foliar spray of nano phosphorus for 2 times. Similar result of advancement was also seen in studies done by Benzon *et al.* (2015).

1000 seed weight is a major yield component which had a range of 22.97g in control to 25.13g in treatment of 100% STD for P+2 sprays of nano-P and all treatments recorded higher values over control. All treatments sprayed with nano-P were at par with the treatment applied with STD only. This indicated that 1 or 2 foliar sprays of nano-P along with 50% or 75% conventional P fertilizer could give similar seed weight, which may be attributed to the better NUE by nano fertilizer. This results are in agreement with Al-Juthery *et al.* (2018), Gomaa *et al.* (2017), Prasad *et al.* (2012), Abdel-Aziz *et al.* (2018) and Kandil *et al.* (2017).

The percentage of filled grains per panicle varied from 87.18 (control) to 91.63 (100% STD for P+2 sprays of nano-P) showing 5.1% increment over control. The treatment T<sub>2</sub> comprising 100% STD (90.44%) was statistically at par with the

remaining treatments except control. 100% STD had shown similar effect as compared to the combination of 100% STD for P and 1 or 2 sprays of nano-P. Benzon et al. (2015) also observed 15.42% increase in total filled grains by combination of full STD of conventional fertilizers with full nano fertilizers over the full STD of conventional ones. This might be due to enhanced seed setting mediated by the nano fertilizer's activities. Similar result was obtained by Kandil *et al.*, 2017 in wheat using mixture of nano- fertilizer + amino acids treatment compared to control. The percentage of unfilled grains per panicle revealed reverse trend of filled grains per panicle as expected.

The mean seed yield per hill and yield per hectare ranged from 10.92g to 15.65g and 17.24 q/ha to 26.23q/ha in control to the treatment with 100% STD and 2 times foliar spray of nano-P showing 43.31% and 52.14% yield increment compared to control respectively whereas, HI showed similar trend ranged from 45.36% to 54.49% with 20.13% advancement in full soil dose with 2 times foliar spray of nano-P as compared to control.

The overall discussion of effect of nano phosphorus on seed yield and yield attributes may be vividly discussed as the treatment T<sub>5</sub> registered the highest and control had the lowest values for these traits. The application of 100% STD only was at par with the treatments containing 50, 75 and 100% STD for P along with 1 or 2 sprays of nano-P, except for yield/ha where 100% STD was higher than 50% STD for P + 2 sprays of nano-P. This suggested that full STD application had similar effect as 50, 75 and 100% STD for P + 1 or 2 sprays of nano-P except for yield/ha whereas it had similar yield upto 75% STD for P + 2 sprays of nano-P and at 50% STD the yield was reduced. This similar trend for yield/ha was due to the same trend observed for all the yield attributes like no. of effective tillers, filled grains/panicle and 1000 seed weight upto 75% STD for P + 2sprays of nano-P and after that probably the cumulative effect of the reduced values of the components had caused reduction in yield. This suggested that the 2 sprays of nano-P could compensate for the correctional nutrition requirements of 25% STD for P fertilizers. Hagab *et al.* (2018) reported that only using 50 or 75% of the recommended rate from nano-source gave higher recovery efficiency of P compared t with 100% ordinary source with almost similar or superior yield. This benefit from nano-P may due to its better NUE as the conventional phosphate fertilizers have lesser NUE reported to be below 20%. Eddy

(2000) advocated foliar fertilization on a viable economic way of supplementing the plant's nutrients for more efficient fertilization. It is thought that foliar application of P could reduce the negative impact of some soil properties. Studies conducted elsewhere demonstrated the positive response of P in wheat and maize yields (Latif *et al.* 1994). This response was evident by the foliar sprays of nano-P with variable dosage of STD for P as done in this study probably due to higher NUE of the nano-fertilizers. According to Benzon *et al.*, 2015, nano fertilizers applied in conjunction with reduced doses of mineral fertilizers were found to be instrumental in boosting yield attributes and grain yield of cereals.

### **5.3 Effect of foliar application of nano phosphorus on seed quality parameters**

In any seed production program, maintenance of sowing quality of seed is the most important consideration. Various physiological parameters accounts for the planting value of seed, most of which are influenced by the environment prevalent during crop growth and post-harvest period. Knowledge of the relationship between nutritional status of soil and plants and the sowing quality of seed is important for the seed production and maintenance of better seed quality. In the present study, the seed quality was assessed by different quality parameters, the results were discussed hereunder.

All treatments with 50, 75 and 100% STD for P+2 sprays of nano-P influenced significantly the seed quality parameters such as germination, field emergence, shoot-root length and dry weight, SVI- I & II as compared to the control. However, all except 50% STD for P + 2 sprays of nano-P (T<sub>7</sub>) had positive response on EC, field emergence, root and shoot length and seedling length indicating that 50% STD for conventional P with 2 sprays of nano-P could not meet the plant's nutritional requirements for these parameters. In almost all cases, 100% STD + 2 sprays of nano-P recorded the highest and the control had the lowest value, suggesting that 100% STD for P + 2 sprays of nano-P could significantly enhance the seed quality parameters due to better NUE of nano-fertilizer.

The seedling vigour indices SVI-I & SVI-II which are the functions of germination, seedling length and dry weight (g or mg) were at par among the treatments with 100% STD(T<sub>2</sub>) and 75% STD for P + 2 sprays of nano-P (T<sub>6</sub>)

recorded the highest, while 50% STD for P + 2 sprays of nano-P had lower indices, suggesting that only 25% of conventional P fertilizers could be replaced by 2 sprays of nano-P to have similar seed vigour indices. This would reduce the doses of mineral fertilizers and environmental pollution and increase the NUE of fertilizers avoiding P fixation in soil.

#### **5.4 Effect of foliar application of nano phosphorus on storability of seeds**

The storability of seeds is decided by the seed quality parameters after the seeds are exposed to accelerated ageing (AA) test. The technology of accelerated ageing test which is a seed vigour test. It is widely accepted as a standard method for predicting relative storability of a seed lot. The performance of seed in terms of germinability, seedling growth rate and vigour after accelerated ageing indicates the relative storage potential of seed lots. Higher germination percentage of aged seeds is an indicator of longer storability.

In this study, all treatments after AA showed reduced values as compared to normal fresh seeds and the parameters such as seed germination(%), field emergence, SV-I & II were positively influenced by all the treatments compared with control. In all parameters, 100% STD + 2 sprays of nano-P recorded the highest value and the control gave the lowest. For most parameters, the application of 100% STD alone registered similar results as with 75% or 100% STD for P + 2 sprays of nano-P except for 50% STD for P + 2 sprays of nano-P. This suggested that the seed vigour of treatments applied with 75% STD for P in conjunction with 2 sprays of nano-P could be same as 100% STD and hence similar storability of seeds. Similar results were obtained by Anandaraj and Natarajan (2017) by conducting a study on seed quality enhancement of onion seeds using ZnO nano particles and reported that seed treatment with nano particles significantly boosted the seed to retain its quality during storage period.

The reduction(%) of these parameters after accelerated ageing were highest in control and 50% STD for P + 2 sprays of nano-P, indicating that all treatments except these two could produce similar vigorous seeds as in sole application of 100% STD of conventional fertilizers. Lower reduction in germination, SVI-I and II after accelerated ageing of seeds was observed in the treatment 100% STD+ 2 sprays of nano-P (T<sub>5</sub>) depicting higher storage life of seeds.

The field experiment was conducted during kharif season of 2020 to study the effect of foliar application of nano phosphorus on plant growth, seed yield and quality of rice (*Oryza sativa* L.). It was conducted in the Central Farm, Regional Research and Technology Transfer Station, Coastal Zone OUAT, Bhubaneswar, Odisha. The field experiment was laid with 7 treatments in RBD with 3 replications. The treatments were: T<sub>1</sub>: Control, T<sub>2</sub>: 100% STD (75:37.5:37.5 NPK kg/ha), T<sub>3</sub>: 100% STD+ spray of water (500 litre/ha) at 14 DAT, T<sub>4</sub>: 100% STD+ spray of nano P (40ml/litre) at 14 DAT, T<sub>5</sub>: 100% STD+ 2 sprays of nano P (40ml/litre) at 14 and 28 DAT, T<sub>6</sub>: 100% NK & 75% P of STD + 2 sprays of nano P (40ml/litre) at 14 and 28 DAT, T<sub>7</sub>: 100% NK & 50% P of STD + 2 sprays of nano P (40ml/litre) at 14 and 28 DAT. The crop was sown on 18th August 2019 and the variety Mandakini was used for this experiment purpose. The plots were treated with different doses of fertilizer (as STD), farm yard manure and seed was treated with vitavax power. The vegetative and reproductive growth behavior of rice in response to foliar nano phosphorus were recorded in the field while the seed quality attributes were evaluated in the laboratory after harvest.

Observations were recorded on plant growth characters viz., days to 50% flowering, days to maturity, plant height, total tillers/hill, total chlorophyll content; yield and yield components viz., effective tillers/hill, panicle length, no of spikelets/panicle, filled & unfilled grains/panicle, 1000-seed weight, seed yield/hill, seed yield/ha, HI and seed quality parameters viz., seed moisture content, electrical conductivity of seed leachate, germination percentage, first count, field emergence, seedling root & shoot length, mean seedling length, mean seedling dry weight, SVI-I and SVI-II. On accelerated aged seeds, observations on germination percentage, seedling root & shoot length, mean seedling length, mean seedling dry weight, SVI-I and SVI-II. The salient outcomes of the investigation are summarized below.

In case of days to 50% flowering, shortest days to flowering (83.33days) was recorded in T<sub>4</sub>, T<sub>5</sub> and T<sub>6</sub>. There was a difference of nearly 1 or 2 days in flowering of various treatments. A maximum of 86 days was taken to 50% flowering by the control.

Significant difference was observed in the trait days to maturity ranging from 107.3 days (T<sub>5</sub>) to 111 days (T<sub>1</sub>) with an overall mean of 109.3 days. Advancement in days to maturity was observed with application of 100% STD + 2 sprays of nano-P (T<sub>5</sub>) followed by T<sub>6</sub> with 100% NK & 75% P of STD + 2 sprays of nano-P. The control T<sub>1</sub> (111 days) was at par with T<sub>7</sub> (110.7 days) and T<sub>3</sub> (110 days).

For plant height, a significant differences among different treatments was observed. The value of the treatments ranged from 119.5 cm (T<sub>5</sub>) to 112 cm (T<sub>1</sub>) with an overall mean of 115.89 cm. The highest plant height was recorded in the treatment T<sub>5</sub> (119.5 cm) with 100% STD and 2 sprays of nano-P followed by T<sub>2</sub> (118.2 cm) with 100% STD which were at par with each other and showing 6.7% and 5.5% taller plants than control (112 cm). The lowest plant height was recorded in control (112 cm). All treatments except T<sub>7</sub> (113.9 cm) were at par with the treatment T<sub>2</sub> with 100% STD (118.2 cm).

The highest value for total tillers/hill was observed in T<sub>5</sub> with 100% STD and 2 sprays of nano-P (8.87) and the lowest was in control (6.67) with an overall mean of 8.05. All treatments registered significantly higher values than control (6.67). All treatments except T<sub>6</sub> (7.60) and control (6.67) were at par with the treatment T<sub>5</sub> (8.87).

The mean value of the treatments for total chlorophyll content was ranged from 2.61 mg/g FW (T<sub>1</sub>) to 3.61 mg/g FW (T<sub>5</sub>) with an overall mean of 3.19 mg/g FW. Numerically higher chlorophyll content was found with 100% STD and 2 sprays of nano-P (3.61 mg/g FW) closely followed by T<sub>6</sub> (3.53 mg/g FW) whereas the lowest total chlorophyll content was recorded in control (2.61 mg/g FW).

The various nano treatments exhibited significant effect on seed yield and yield components of rice. There was a significant variation was found among different treatments for effective tillers/hill. All treatments registered significantly higher values than control (5.80). The treatment comprising 100% STD with 2 spray of nano-P (T<sub>5</sub>) showed highest no. of effective tillers (8.07) which is 31.1% higher than the control (5.80).

The highest panicle length was observed in the treatment T<sub>5</sub> with 100% STD and 2 sprays of nano-P (24.73 cm) followed by T<sub>3</sub> (24.47cm), T<sub>6</sub>(24.33cm), T<sub>2</sub>(24.27cm) whereas lower panicle length was recorded in

control(20.87cm). All treatments registered significantly higher values than control (20.87 cm) and were statistically at par with T<sub>2</sub> (100% STD).

Numerically higher no. of spikelets/panicle (133.4) were found in treatment with 100% of STD and 2 foliar application of nano phosphorus and the lowest spikelets/panicle of 121.0 was recorded in the control. Treatments T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> had shown significantly higher values over control (121.0). All treatments were statistically at par with the treatment T<sub>2</sub> applied with 100% STD.

A significant variation for filled grains/panicle was registered among the treatments with various doses of STD and foliar nano phosphorus. The mean value of the treatments ranged from 87.18% (T<sub>1</sub>) to 91.63% (T<sub>5</sub>) with an overall mean of 89.86%. The maximum filled grains/panicle was recorded in the treatment T<sub>5</sub> (91.63%) which was 5.1% higher than control (87.18%) whereas lowest filled grains/panicle was recorded in the treatment T<sub>1</sub>(87.18%).

Comparatively higher yield can be expected if the percentage of unfilled grains/panicle is in lower number. In the present investigation it was reported that all treatments showed significantly lower values than control (11.15%). The treatment T<sub>5</sub> (8.37%) indicated lowest percentage of unfilled grains per panicle which was 24.93% lower than control (11.15%) followed by T<sub>7</sub> (8.70%) whereas the highest percentage of unfilled grains/panicle was recorded in treatment T<sub>1</sub> (11.15%). The treatment T<sub>2</sub> comprising 100% STD (9.22%) was also statistically at par with the remaining treatments having variable dosage of STD with nano-P except control.

In the present study, a positive effect of spray of nano phosphorus can be seen on 1000-seed weight. The mean value of the treatments ranged from 22.97g (T<sub>1</sub>) to 25.13g (T<sub>5</sub>) with an overall mean of 24.54g. The treatment T<sub>5</sub> with 100% STD and 2 sprays of nano phosphorus indicated maximum 1000-seed weight(25.13g) with 9.4 % increment over control whereas the lowest 1000-seed weight was recorded in control (22.97g). The treatment T<sub>2</sub> (24.70 g) comprising 100% STD was statistically at par with the remaining treatments having variable dosage of STD with nano-P except control.

Seed yield per hill exhibited significant variation among the different treatments as revealed by the ANOVA for this trait in this study. All treatments

showed significantly higher values than control (10.92 g). The maximum seed yield/hill was recorded in treatments T<sub>5</sub> (15.65 g) followed by T<sub>4</sub> (15.20 g) which had 43.31% and 39.19% higher seed yield/hill than control (10.92 g). The lowest seed yield/hill was recorded in treatment T<sub>1</sub> (10.92 g). Like test weight, the treatment T<sub>2</sub> (14.28 g) comprising 100% STD was also at par with the remaining treatments including T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> except control.

The most important economic character, seed yield/ha registered significant differences among the different treatments. Its mean values for various treatments varied from 17.24 q/ha in T<sub>1</sub> (control) to 26.23 q/ha in T<sub>5</sub>, with an overall mean of 23.92 q/ha. The treatment T<sub>5</sub> (26.23 q/ha) recorded the highest seed yield closely followed by T<sub>4</sub> (25.82 q/ha) which had 52.14% and 49.77% higher yield than control (17.24 q/ha). Like test weight and seed yield/hill, the treatment T<sub>2</sub> (24.94 q/ha) applied with 100% STD was also at par with the remaining treatments including T<sub>5</sub> (26.23 q/ha) and T<sub>6</sub> (24.72 q/ha), but significantly higher than T<sub>7</sub> (50% STD for P + 2 sprays of nano-P at 14 and 28 DAT) which yielded 23.26 q/ha.

The present study revealed the presence of a positive effect of foliar spray of nano-phosphorus on HI. The highest HI was recorded in the treatment T<sub>5</sub> (54.49%) with 100% STD and 2 times spray of nano-p followed by T<sub>4</sub> (54.30%) and T<sub>6</sub>(54.01%) showing 20.13%, 19.71% and 19.07% higher HI(%) than control (45.36%), whereas the lowest was in control (45.36%). All treatments had significantly higher values than control. The treatment T<sub>2</sub> with 100% STD (52.11%) was at par with the remaining treatments including T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> except control.

Discussing the seed quality parameters, a non-significant variation was found for seed moisture content. The treatments mean varied from 11.14% (T<sub>7</sub>) to 12.07% (T<sub>5</sub>) with an overall mean of 11.57%. Numerically higher percentage of seed moisture content was indicated in the treatment T<sub>5</sub> (12.03%) with 100% STD and 2 sprays of nano-P followed by T<sub>3</sub> (11.82%), T<sub>6</sub> (11.73%) T<sub>4</sub> (11.70%), whereas lowest seed moisture content was recorded in the treatment T<sub>7</sub> (11.14 %) with 100% NK & 50% P of STD + 2 times spray of nano-P .

The study of effect of nano phosphorus on electrical conductivity of seed leachate showed significant variation where the mean value of the treatments ranged from 0.050 dS/m ( T<sub>7</sub>) to 0.073 dS/m (T<sub>1</sub>) with an overall mean of 0.06 dS/m.

Significantly lower values was observed in all treatments than T<sub>1</sub> (0.073 dS/m). The treatment T<sub>2</sub> (0.067 dS/m) was at par with T<sub>3</sub> (0.062 dS/m) while it was significantly lower than T<sub>4</sub> to T<sub>7</sub>, indicating better vigour of these treatments compared to T<sub>2</sub>. The minimum electrical conductivity of seed leachate was recorded in treatment T<sub>7</sub>(0.050 dS/m).

In the present study, it was recorded that all treatments showed significantly higher values over control (82.00 %) which depicted the minimum percentage for seed germination. The maximum seed germination was recorded in the treatment T<sub>5</sub> (93.00 %) with 100% STD and 2 times foliar spray of nano-P which was 13.41 % higher than control (82.00 %). All treatments including T<sub>6</sub> and T<sub>7</sub> except in control had significantly higher values than T<sub>2</sub> (89.07%) with 100% STD only.

First count (%) also registered significant variation among the different treatments in the study of the effect of nano phosphorus on this trait showing the maximum first count in the treatment T<sub>4</sub> (73.67 %) with 100% STD and single spray of nano-P which was 7.23 % higher than control (67.33 %) whereas the lowest first count value was recorded in treatment T<sub>1</sub> (55.15 %). All treatments including T<sub>6</sub> and T<sub>7</sub> except control were at par with T<sub>2</sub> (71.00 %) with 100% STD only.

The mean value for field emergence was ranged from 79.00 % (T<sub>1</sub>) to 90.67 % (T<sub>5</sub>) with an overall mean of 86.72%. All treatments had shown significantly higher values over T<sub>1</sub> (88.9 %) for this trait. The maximum field emergence was recorded in the treatments T<sub>5</sub> (90.67 %) followed by T<sub>4</sub> (88.67) and T<sub>3</sub>(88.33) showing 14.77%, 12.24% and 11.81%, higher field emergence than control respectively. The lowest field emergence was recorded in treatment T<sub>1</sub> (79.00 %). Most of the treatments including T<sub>6</sub> and T<sub>7</sub> receiving nano-P sprays but except control were significantly superior to 100% STD only (93.1%).

Shoot length is an important parameter which reflects early seedling growth during germination of crop seeds. In the present investigation, this parameter was measured on the final day of germination count and recorded highest shoot length in the treatment T<sub>6</sub> (8.95 cm) which was sprayed for 2 times nano-P with 100% NK and 75% P of STD followed by T<sub>4</sub> (8.93 cm) and T<sub>2</sub> (8.87 cm), whereas lowest shoot length was recorded in the treatment control (7.77 cm). All treatments including T<sub>6</sub> and T<sub>7</sub> except control were at par with T<sub>2</sub> (8.87 cm).

The maximum root length was recorded in the treatment T<sub>5</sub> (15.20 cm) which was 17.83 % higher than the control, followed by T<sub>2</sub> (14.97 cm) and T<sub>3</sub> (14.69 cm) showing 16.05 % and 13.88 %, higher root length than control, respectively. The lowest seedling root length was recorded in treatment T<sub>1</sub> (12.90 cm). All treatments including T<sub>6</sub> except control and T<sub>7</sub> were statistically at par with T<sub>2</sub> (14.97 cm).

A significant variation was found among the different treatments for seedling length. All treatments except T<sub>7</sub> had significantly higher values for this trait as compared to T<sub>1</sub> (20.67 cm). The maximum seedling length was recorded in the treatments T<sub>5</sub> (23.94 cm) followed by T<sub>2</sub> (23.83 cm), T<sub>4</sub>(23.50 cm) and T<sub>6</sub>(23.47 cm) which were at par with each other and showed 16.72 %, 15.29 %, 13.69 % and 13.55% respectively, higher seedling length than control. The lowest seedling length was recorded in treatment T<sub>1</sub> (20.67 cm).

The mean value of the treatments for seedling dry weight was varied from 63.9 mg (T<sub>3</sub>) to 75.5 mg (T<sub>5</sub>) with an overall mean of 70.90 mg. Maximum seedling dry weight was indicated in the treatment T<sub>5</sub> (75.5 mg) followed by T<sub>4</sub> (74.2 mg) which were at par with each other showing 18.15% and 16.12% higher weight than control whereas lowest value for seedling dry weight was recorded in control(63.9 mg).

The performance of crop varieties also largely depend upon seed vigour (Mathews, 1993). Therefore any study involving seed production and quality assessment, due emphasis is given on seed vigour. The common parameter used to represent seed vigour is the seed vigour index (SVI) which is measured by integrating two other physiological quality parameters germination percent and seedlings length (SVI-I) or dry weight (SVI-II). In the present investigation both the parameters like SVI-I & II showed maximum and minimum value with the treatment T<sub>5</sub> and T<sub>1</sub> as (2226.6 & 7.02) and (1694.3 & 5.24) respectively.

The accelerated ageing (AA) vigour test provides valuable information on both seed storability and field seedling emergence potentials. In this study results were found as the maximum seed germination in the treatment T<sub>5</sub> (87.67 %) which was 17.40 % higher than control, whereas the lowest seed germination was recorded in control (74.67 %). The treatment T<sub>2</sub> (85.00%) was statistically at par with remaining treatments except control for seed germination.

Seedling field emergence after accelerated ageing indicated significant variation among the different treatments showing maximum field emergence in the treatment T<sub>5</sub> (87.33 %) which was 18.54 % higher than control, whereas the lowest seed germination was recorded in control (73.67 %). The maximum and minimum value for SVI-I & II after AA test was recorded in the treatment T<sub>5</sub> as 1880.2 & 6.02 whereas in control as 1298.5 & 4.30 respectively.

However, in the present course of study for the effect of foliar spray of nano phosphorus, significant reduction in germination percentage and seedling vigour indices were noticed after accelerated ageing. Relatively lower germination, SVI-I and II were noticed in the treatment with 100% STD and 2 sprays of nano phosphorus(T<sub>5</sub>) closely followed by T<sub>4</sub> and T<sub>7</sub>(5.00), indicating their more tolerance to stress and better storability of seeds.

Considering growth parameters, yield performance and seed quality attributes, it may be concluded that in almost all cases the application of 100% STD @ 75:37.5:37.5 NPK kg/ha + 2 sprays of nano-P (40 ml/litre) at 14 & 28 DAT was found to be most effective in giving higher plant growth, seed yield (26.23 q/ha) and better seed quality parameters in rice cv. Mandakini, So, if nano-fertilizer could be made available at similar price of conventional fertilizers, the use of nanofertilizer will reduce the cost of seed production and pollution will be minimized.

## REFERENCES

---

- Abdel-Aziz HMM, Hasaneen MNAG and Omer AM.2018.Foliar application of nano chitosan NPK fertilizer improves the yield of wheat plants grown on two different soils, *Egyptian Journal of Experimental Biology (Botany)*, **14**(1): 63-72.
- Anderson AB.1969. Relationship of glucose metabolism to germinability and vigour in barley and wheat seeds, *Crop Sci.*,**9**: 732-737.
- Anderson AB, A and Anderson JP. 1973. Vigour deterioration in soybean by multiple criteria, *Crop Sci*,**13**: 630-637.
- Acharya P, Jayaprakasha GK, Crosby K and Patil BS.2014.Nanopriming: An Effective Technique to Improve Seed Germination, Growth and Quality in Onion (*Allium cepa* L.), *Vegetable and Fruit Improvement Center, Department of Horticultural Sciences Texas A&M University, College Station, TX* :77845-2119.
- Afify RR,El-Nwehy SS, Bakry AB and Abd El-Aziz ME.2019.Response of peanut (*Arachis hypogaea* L.) crop grown on newly reclaimed sandy soil to foliar application of potassium nano-fertilizer, *Middle East Journal of Applied*, **9**(1): 78-85.
- Aguilar-Garcia C, Gavino G, Baragaño-Mosqueda M, Hevia P and Gavino V. 2007. Correlation of tocopherol, tocotrienol,  $\gamma$ -oryzanol, and total polyphenol content in rice bran with different antioxidant capacity assays, *Food Chemistry*,**102**: 1228-1232.
- Alam MM, Hassanuzzaman M and Nahar K. 2009. Tiller dynamics of three irrigated rice varieties under varying phosphorus levels, *Am– Eurasian J. Agron*,**2**(2): 89-94.
- Alinajati S and Mirshekari B. 2011. Effect of phosphorus fertilization and seed bio fertilization on harvest index and phosphorus use efficiency of wheat cultivars,*J. Food Agric. Environ*,**9**(2): 388-397.

- Al-Juthery HWA, Habeeb KH, Altaee FJK, AL-Taey DKA and Al-TawahaARM. 2018. Effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat, *Bioscience Research*, **15**(4): 3988-3997.
- Alshaal T and El-Ramady H. 2017. Foliar Application: from Plant Nutrition to Biofortification, *The Environment, Biodiversity and Soil Security*, **1**:71-83.
- Anandaraj K and Natarajan K. 2017. Effect of nanoparticles for seed quality enhancement in onion [*Allium cepa* (Linn) cv. CO (On)] 5, *International Journal of Current Microbiology and Applied Sciences*, **6**(11) : 3714-3724.
- Armin M, Akbari S and Mashhadi S. 2014. Effect of time and concentration of nano-Fe foliar application on yield and yield components of wheat, *International Journal of Biosciences*, **4**(9): 69-75.
- Azimi R, Feizi H and HosseiniMK. 2013. Can bulk and nanosized titanium dioxide particles improve seed germination features of wheatgrass (*Agropyron desertorum*), *Notulae Scientia Biologicae*. **5**(3): 325-331.
- Bakhtiari M, Moaveni P and Sani B. 2015. The effect of iron nanoparticles spraying time and concentration on wheat, *Biological forum*, **7**(1): 679-683.
- Baruah S. and Dutta J. 2009. Nanotechnology applications in sensing and pollution degradation in agriculture, *Env. Chem. Letters J*, **7**: 191-204.
- Benzon HRL, Rubenecia MRU, Ultra VU Jr. and Lee SC. 2015. Nano-fertilizer affects the growth, development, and chemical properties of rice, *International Journal of Agronomy and Agricultural Research*, **7**(1):105-117.
- Bray's RA and Kurtz LT. 1945. Determination of total organic and available forms of phosphorus in soil, *Soil Science*, **59**: 39-45.
- Burris JS. 1980. Maintenance of soyabean seed quality in storage as influenced by moisture, temperature and genotype, *Iowa State J. Res*, **54**: 337-389.
- Chiranjeevi N, Kumar PA, Jayalakshmi RS, Prasad KVH and PrasadTNVKV. 2018. Effect of seed treatment and spray with biosilver nano particles and bio control agents on defence related enzymes activity in rice

seedlings and plant growth parameters in vitro, *International Journal of Chemical Studies*, **6**(3): 882-890.

Choudhary DK, Karmakar S and Kumar B.2018.Intercession of Legume Based Inter-Cropping and Nano Phosphorus as Managerial Input for Upland of Jharkhand, *Chem. Sci. Rev. Lett*, **7**(28):941-946.

Christianson C and Bruce RD. International fertilizer development center, Muscle Shoals, ALA, USA.

Crista F, Isidora R, Florin S, Laura C and Adina B. 2012. Influence of NPK fertilizers upon winter wheat grain quality, *Research Journal of Agricultural Science*, **44** (3):30-35.

Davarpanah S, Tehranifara A, Davarynejad G, Abadía J and Khorasani R, 2016, Effects of foliar applications of zinc and boron nanofertilizers on pomegranate (*Punicagranatum* cv. *Ardestani*) fruit yield and quality, *Scientia Horticulturae*, **210**: 1-8.

Delfani M, Firouzabadi MB, Farrokhi N and Makarian H. 2014. Some physiological responses of black-eyed pea to iron and magnesium nanofertilizers, *Communications in Soil Science and Plant Analysis*, **45**(4): 530-540.

Delouche JC and Baskin CC. 1973.Accelerated ageing techniques for predicting the relative storability of seed lots, *Seed Sci. and Tech*, **1**: 427-452.

Delouche JC, Baskin CC and Rushing TT. 1967. Predicting relative storability of crop seed lots, Seed Tech Special Report, Mississippi State University, Mississippi State, MS.

Dimkpa CO, McLean JE, Britt DW and Anderson AJ. 2015. Nano-CuO and interaction with nano-ZnO or soil bacterium provide evidence for the interference of nanoparticles in metal nutrition of plants, *Ecotoxicology*, **24**,119-129.

DOI: <http://dx.doi.org/10.5772/intechopen.89089>

- Dong Z, Wu L, Chai J, Zhu Y, Chen Y and Zhu Y. 2015. Effects of nitrogen application rates on rice grain yield, nitrogen-use efficiency, and water quality in paddy field, *Commun. Soil Sci. Plant Anal*, **46**(12): 1579-1594.
- Drostkar E, Talebi R and Kanouni H. 2016. Foliar application of Fe, Zn and NPK nano-fertilizers on seed yield and morphological traits in chickpea under rainfed condition, *Journal of Research in Ecology*, **4**(2):221-228.
- Duraisamy K, Kathiresan, M and Narayanaswamy R. 2001. In: Rice cultivation in Tamilnadu, *Golden net pub*, Tiruchirapalli.
- Ghasemi M, Noormohammadi G, Madani H, Mobasser H and Nouri M. 2017. Effect of foliar application of zinc nano oxide on agronomic traits of two varieties of rice (*Oryzasativa* L.), *Crop Research*, **52**(6): 195-201.
- Gomaa MA, Radwan FI, Kandil EE and Al- Challabi DHH. 2017. Comparison of some New Maize Hybrids Response to Mineral Fertilization and some nanofertilizers, *Alexandria Science Exchange Journal*, **3**(83).
- Hadis H, Gashaw M and Wassie H. 2018. Response of bread wheat to integrated application of vermicompost and NPK fertilizers. *African Journal of Agricultural Research*. **13**(1): 14-20.
- Hagab RH, Kotp YH and Eissa D. 2018. Using nanotechnology for enhancing phosphorus fertilizer use efficiency of peanut bean grown in sandy soils, *J. Adv. Pharm. Edu. Res*, **8**(3):59-67.
- Harsini MG, Habibi H and Talaei GH. 2014. Study the effects of iron nano chelated fertilizers foliar application on yield and yield components of new line of wheat cold region of Kermanshah province, *Agriculture Advances*, **3**(4): 95-102.
- Hassan F, Parviz R, Moghaddam N, Shahtah M and Amir F. 2012. Impact of Bulk and Nanosized Titanium Dioxide (TiO<sub>2</sub>) on Wheat Seed Germination and Seedling Growth, *Biol Trace Elem Res*, **146**:101–106.
- Hussien MM, El-Ashry SM, Haggag WM and Mubarak DM. 2015. Response of Mineral Status to Nano-Fertilizer and Moisture Stress during Different Growth Stages

of Cotton Plants, *International Journal of Chem Tech Research*, **8**(12):643-650.

- Iqbal MA .2019. Nano-Fertilizers for Sustainable Crop Production under Changing Climate: A Global Perspective.
- ISTA (International Seed Testing Association). 1996. International rules for seed testing rules, *Seed Science and Technology*, **13**: 299-513.
- Jaberzadeh A, Moaveni P, Moghadam H R T and Zahedi H, 2013. Influence of bulk and nanoparticles titanium foliar application on some agronomic traits, seed gluten and starch contents of wheat subjected to water deficit stress, *Notulae Botanicae Horti Agrobotanici*, **41**(1): 201-207.
- Jackson ML. 1973. Soil Chemical Analysis, Prentice-Hall of India Pvt. Ltd., New Delhi.
- Jafarzadeh R, Jami M and Hokmabadi M. 2013. Response of yield and yield components in wheat to soil and foliar application of Nano Potassium fertilizer, *Journal of crop production research (Environmental stresses in Plant Sciences)*, **5**(2): 189-197.
- Janmohammadi M, Amanzadeh T, Sabaghnia N and Dashti S. 2016. Impact of foliar application of nano micronutrient fertilizers and titanium dioxide nanoparticles on the growth and yield components of barley under supplemental irrigation, *Acta Agriculturae Slovenica*, **107**(2): 265-276.
- Jassim RAH, Kadhem HN and Nooni GB. 2019. Impact of levels and time of foliar application of nano fertilizer (super micro plus) on some components of growth and yield of rice (*Oryza sativa* L.), *Plant Archives*, **19**(1):1279-1283.
- Kandil EE and Marie EAO. 2017. Response of Some Wheat Cultivars to Nano, Mineral Fertilizers and Amino Acids Foliar Application, *Alexandria Science Exchange Journal*, **38**(1):54
- Khuang TQ, Huan TT and Hach CV. 2008. Study on fertilizer rates for getting maximum grain yield and profitability of rice production, *J. Agron*, **16**: 93-99.
- Kumar R, Pandey DS, Singh VP and Singh IP. 2014. Nano-technology for better fertilizer use (Research Experiences at Pantnagar), *Research Bulletin no. 201*.

- Liakas V, Rauckis V and Paltanavius V. 2001. Influence of phosphorus and potash fertilizers on germination, tillering and overwintering of winter wheat, *Mokslo Darbai*, **74**, 3-12.
- Liu H. 2007. Whole grain phytochemicals and health. *Journal of Cereal Science*, **46**: 207-219.
- Liu R and Lal R. 2015. Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions—A review, *Science of the Total Environ*, **514** : 131-39.
- Liu R and Lal R. 2014. Synthetic apatite nanoparticles as a phosphorus fertilizer for soybean (*Glycine max*), *Scientific Reports*, **4**:56-86.
- Magda S and Hussein MM. 2015. Usage of the nano phosphorous fertilizers in enhancing the corn crop and its effect on corn borers infestations after fungi treatments, *International Journal of Chem Tech Research*, **8(9)**:167-173.
- Mahakham W, Sarmah AK, Maensiri S and Theerakulpisut P. 2017. Nanopriming technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles, *Scientific Reports*, **7**: 8263.
- Mahakham W, Theerakulpisut P, Maensiri S, Phumying S and Sarmah AK. 2016. Environmentally benign synthesis of photochemicals capped gold nanoparticles as nanopriming agent for promoting maize seed germination, *Science of Total Environment*, **573**:1089-1102.
- Mahil EIT and Aravinda Kumar BN. 2019. Foliar application of nanofertilizers in agricultural crops- A review, *J. Farm Sci*, **32(3)**:239-249.
- Mandeh M, Omidi M and Rahaie M. 2012. In Vitro Influences of TiO<sub>2</sub> Nanoparticles on Barley (*Hordeum vulgare* L.) Tissue Culture, *Biological Trace Element Research*, **150**, p. 376-380.
- Marimuthu S and Surendran U. 2015. Effect of nutrients and plant growth regulators on growth and yield of black gram in sandy loam soils of Cauvery new delta zone, India, *Cogent Food and Agriculture*, **1(1)**: 101-415.

- Marzouk NM, Abd-Alrahman HA, EL-Tanahy AMM and Mahmoud SH. 2019. Impact of foliar spraying of nano micronutrient fertilizers on the growth, yield, physical quality, and nutritional value of two snap bean cultivars in sandy soils, *Bulletin of the National Research Centre*, **43**:84.
- Mazumdar H and Ahmed GU. 2011. Synthesis of silver nanoparticles and its adverse effect on seed germinations in *Oryza sativa*, *Vigna radiata* and *Brassica campestris*, *Int. J. Advanced Biotech. & Res*, **2**(4): 404-413.
- Meena Dharam Singh. 2015. Studies on the effect of time of application and concentration of nano zinc sulphide (nZS) on the growth and yield of sunflower (*Helianthus annuus* L.), M. Sc. (Agri) Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.
- Mir S, Sirousmehr A and Shirmohammadi E. 2015. Effect of nano and biological fertilizers on carbohydrate and chlorophyll content of forage sorghum (Speedfeed hybrid), *International Journal of Biosciences*, **6**(4): 157-164.
- Morteza E, Moaveni P, Farahani HA and Kiyani M. 2013. Study of photosynthetic pigments changes of maize (*Zea mays* L.) under nano TiO<sub>2</sub> spraying at various growth stages, *Springer Plus*, **2**(1): 1-5.
- Naderi MR and Danesh-Sharaki A. 2013. Nano fertilizers and their role in sustainable agriculture, *International Journal of Agriculture and Crop Sciences*, **5**(19): 2229-2232.
- Nair R, Varghese SH, Nair BG, Maekawa T, Yoshida Y and Kumar DS. 2010. Nanoparticulate material delivery to plants, *Plant Science*, **179**: 154–163.
- Noshad A, Hetherington C and Iqbal M. 2019. Impact of AgNPs on Seed Germination and Seedling Growth: A Focus Study on Its Antibacterial Potential against *Clavibacter michiganensis* subsp. *michiganensis* Infection in *Solanum lycopersicum*, *Journal of Nanomaterials*, **12**.
- Peyvendi M, Parande H and Mirza M. 2011. Comparison of the effects of nano-iron chelated with iron chelate on growth parameters and antioxidant and enzyme activity of *Ocimum basilicum*, *New Cellular and Molecular Biotechnology Magazine*, **1**(4): 89-98.

- Piper CS. 1966. Sprotein and Plant Analysis, Publ. Academic Press. New York. pp 47-77.
- Prasad TN, Sudhakar VKV, Sreenivasulu P, Latha Y, Munaswamy P, Raja Reddy VR, Sreeprasad K, Sajanlal TS and Pradeep T. 2012. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut, *J. plant nutri*,**35**: 905-927.
- Qureshi A, Singh DK and Dwivedi S.2018.Nano-fertilizers: A Novel Way for Enhancing Nutrient Use Efficiency and Crop Productivity, *International Journal of Current Microbiology and Applied Sciences*, **7**(2):3325-3335.
- Raliya R, Nair R, Chavalmane S, Wang W N and Biswas P. 2015. Mechanistic evaluation of translocation and physiological impact of titanium dioxide and zinc oxide nanoparticles on the tomato (*Solanum lycopersicum* L.) plant, *Metallomics*, **7**: 1584-1594.
- Randhawa NS and Velayutham M. 1989. In: Proceeding of Colloquium on soil fertility and fertilizer management in semi arid tropical India (Ed.)
- Rangaraj S, Gopalu K, Rathinam, Venkatachalam Rand Narayanasamy K. 2012. Silica nanoparticles for increased silica availability in maize (*Zea mays* L.) seeds under hydroponic conditions, *Current Nanoscience*, **8**: 902-908.
- Rathinam Y, Viswanathan E, Venkatachalam R, Narayana SKand Periasamy P. 2011. Influence of nano silica powder on the growth of maize crop (*Zea mays* L.),*Int. J. Green Nanotech*, **3**:180–190.
- Rathnayaka RMNN, Mahendran S, Iqbal YB and Rifnas LM.2018.Influence of Urea and Nano-Nitrogen Fertilizers on the Growth and Yield of Rice (*Oryzasativa* L.) Cultivar ‘Bg 250’,*International Journal of Research Publications*,**5**(2).
- Rezaei M and Abbasi H. 2014. Foliar application of nanochelate and non-nanochelate of zinc on plant resistance physiological processes in cotton (*Gossipium hirsutum* L.),*Iranian Journal of Plant Physiology*, **4**(4): 1137-1144.
- Rietra RPJ, Marius JH, Chistian OD and Prem SB. 2017. Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency, *Communication in soil science and plant analysis*, **48**(16):1895–1920.

- Rostami M, Movahedi Z, Davari M R and Siahpoosh S. 2017. Effect of foliar application of biofertilizer and nano-fertilizers on morpho-physiological characteristics of peppermint (*Mentha piperita* L.), In: Tropentag2017-Future Agriculture: Social ecological Transitions and Bio-cultural shifts, Malayer University, Iran.
- Sabbour M and Hussein MM.2015.Usage of the nano phosphorous fertilizers in enhancing the corn crop and its effect on corn borers infestations after fungi treatments, *International Journal of Chem Tech Research*, **8**(9):167-173.
- Saigusa M. 2000. Broadcast application versus band application of polyolefin-coated fertilizer on green peppers grown on andisol, *J. Plant Nutr*, **23**(10): 1485-1493.
- Salama HMH. 2012. Effects of silver nanoparticles in some crop plants, Common bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.), *Internat. Res. J. of Biotechnol*, **3**(10):190-197.
- Sandeep A, Sharma P, Kumar S, Nayan R, Khanna PKand Zaidi MGH. 2012. Gold-nanoparticle induced enhancement in growth and seed yield of *Brassica juncea*, *Plant Growth Regul*, **66**: 303–310.
- Sani B. 2012. Energy efficiency management (EEM) by use of nanoparticles in maize seedling growth, *European Journal of Experimental Biology*, **2**(5): 1918-1921.
- Sharifi R, Mohammadi K and Rokhzadi A. 2016. Effect of seed priming and foliar application with micronutrients on quality of forage corn (*Zea mays*), *Environmental and Experimental Biology*, **14**: 151-156.
- Shyla KK and Natrajan N. 2014. Customizing zinc oxide, silver and titanium dioxide nanoparticles for enhancing groundnut seed quality, *Indian Journal of Science and Technology*, **7**: 1376–1381.
- Singh S. 2012. Achieving Second Green Revolution through Nanotechnology in India, *Agric. Situations India*, 545-572.
- Sohair EED, Abdall AA, Amany AM, FaruqueHMd, Houda RA.2018. Evaluation of Nitrogen, Phosphorus and Potassium Nano-Fertilizers on Yield, Yield

- Components and Fiber Properties of Egyptian Cotton (*Gossypium barbadense* L.), *J Plant Sci Crop Protec*, **1**(2): 208.
- Soliman AS, Hassan M, Abou-Elella F, Hanafy Ahmed AH and El-Feky SA. 2016. Effect of Nano and Molecular Phosphorus Fertilizers on Growth and Chemical Composition of Baobab (*Adansonia digitata* L.), *Journal of Plant Sciences*, **11** (4): 52-60.
- Song U, Shin M, Lee G, Roh J, Kim Y, Lee EJ. 2013. Functional Analysis of TiO<sub>2</sub> Nanoparticle Toxicity in Three Plant Species, *Biological Trace Element Research*, **155**, p. 93-103.
- Subbiah BV and Asija GL. 1956. A rapid procedure for the determination of available nitrogen in soils, *Curr. Sci*, **25**: 259-60.
- Swain RK, Padhiary AK, Behera S, Mishra SP, Jena M, Swain SC and Rout SK. 2017. Morpho Physiological Traits of Some Rice Varieties in Response to Shallow Water Depth, *Int. J. Curr. Microbiol. App. Sci*, **6**(11): 3950-3957.
- Swetha Kumari M, Rao PC, Padmaja G, Ramulu V, Saritha JD and Ramakrishna K. 2017. Effect of bio and nano phosphorus on yield, yield attributes and oil content of groundnut (*Arachis hypogaea* L.), *Environment Conservation Journal*, **18**(3): 21-26.
- Tapan A, Kundu S and Subba RA. 2013. Impact of SiO<sub>2</sub> and Mo Nano Particles on Seed Germination of Rice (*Oryza sativa* L.), *International J. Agric. Food Sci. Technology*, **4**(8): 809-816.
- Tarafdar JC and Raliya R. 2013. ZnO nanoparticle synthesis and its effect on phosphorus mobilizing enzyme secretion and gum content in cluster bean, *Agriculture Research*, **2**(1): 48-57.
- Tarafdar JC, Raliya R, Mahawar H and Rathore I. 2014. Development of zinc nanofertilizer to enhance crop production in pearl millet (*Pennisetum americanum*), *Agricultural Research*, **3**(3): 257- 262.
- Tarafdar JC, Rathore I and Thomas E. 2015. Enhancing Nutrient Use Efficiency through Nano Technological Interventions, *Indian J. Fert*, **11** (12): 46-51.

- Upadhyaya H, Begum L, Dey B, Nath PK and Panda SK.2017.Impact of Calcium Phosphate Nanoparticles on Rice Plant, *Journal of Plant Science and Phytopathology*,**1**:001-010.
- Ushahra J, Kushwaha HB and Malik CP.2014.Biogenic nanoparticle-mediated augmentation of seed germination, growth and antioxidant level of *Eruca sativa* Mill. Varieties, *Appl. Biochem. Biotechnol*, **174**:729–738.
- Vafa ZN, Sirousmehr AR, Ghanbari A, Khammari E and Falahi N. 2015.Effect of nano-zinc and humic acid in quantitative and qualitative characteristics of savory (*Satureja hortensis* L.), *International Journal of Biosciences*, **6**: 124-136.
- Villagomez EM, Tellez LIT, Merino FCG, Villa MS, Gracia PS and Mendez MAA.2019.Nanophosphorus fertilizer stimulates growth and photosynthetic activity and improves P status in rice, *Journal of Nanomaterials*, **11**.
- Vishekaiia ZR, Soleimania A, Fallahib E, Ghasemnezhad M and Hasanid.2019.The impact of foliar application of boron nano-chelated fertilizer and boric acid on fruit yield, oil content, and quality attributes in olive (*Olea europaea* L.), *Scientia Horticulturae*, **257** :108689.
- Yugandhar P and Savithramma N. 2013.Green synthesis of calcium carbonate nanoparticles and their effects on seed germination and seedling growth of *Vigna mungo* (L.) Hepper, *International Journal of Advanced Research*. **1**(8): 89-103.
- Ziadi N, Bélanger G, Cambouris AN, Tremblay N, Nolin MC and Claessens A. 2008.Relationship between phosphorus and nitrogen concentrations in spring wheat, *Agron. J*, **100** (1):80-86.