# AGRONOMIC BIOFORTIFICATION AND ENHANCEMENT OF PRODUCTIVITY IN BREAD WHEAT (*Triticum aestivum* L.) VARIETIES

**Dissertation**

**Submitted to the Punjab Agricultural University**
**in partial fulfillment of the requirements**
**for the degree of**

**DOCTOR OF PHILOSOPHY**
**in**
**AGRONOMY**
**(Minor Subject: Botany)**

**By**

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**(L-2010-A-5-D)**

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**PUNJAB AGRICULTURAL UNIVERSITY**
**LUDHIANA-141 004**

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## CERTIFICATE I

This is to certify that the thesis entitled, **"Agronomic biofortification and enhancement of productivity in bread wheat (*Triticum aestivum* L.) varieties"** submitted for the degree of **Doctor of Philosophy** in the subject of **Agronomy** (Minor subject: **Botany**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr Pardeep Kumar (L-2010-A-5-D)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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**Major Advisor**
**(Dr. R. S. Uppa)**
Professor of Agronomy
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## CERTIFICATE II

This is to certify that the dissertation entitled, **"Agronomic biofortification and enhancement of productivity in bread wheat (*Triticum aestivum* L.) varieties"** submitted by **Mr Pardeep Kumar** (Admn No. **L-2010-A-5-D)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in the subject of **Agronomy** (Minor subject: **Botany**) has been approved by the Student's Advisory Committee after an oral examination on the same.

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*With Thou blessings, a tiny seed developed into a tree."*

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**Dated: _____** **Pardeep Kumar**

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## ABSTRACT

The present study entitled, "Agronomic biofortification and enhancement of productivity in bread wheat (*Triticum aestivum* L.) varieties" was conducted at Punjab Agricultural University, Ludhiana during *rabi* 2011-12 and 2012-13 under timely-sown, irrigated conditions on loamy sand soil (*Typic Ustochrept*) testing near normal in pH, low EC, low in available N, medium in available P and K, low in available Cu and Mn. The experiment I was laid out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with nine nutrient management treatments ($T_1$: NPK alone as control, $T_2$: NPK + Zn (s), $T_3$: NPK + Zn (f), $T_4$: NPK + Zn (s) + Zn (f), $T_5$: NPK + Fe (f), $T_6$: NPK + Zn (s) + $N_{50}$, $T_7$: NPK + $N_{50}$ + Zn (f), $T_8$: NPK + Zn (s) + $N_{50}$ + Zn (f) and $T_9$: NPK + $N_{50}$ + Fe (f) in the sub plots. In the experiment II, the three varieties were sown in the main plot as stated above. In the sub plots, seven nutrient treatments were $T_1$: NPK (Control), $T_2$: NPK + Mn (f), $T_3$: NPK + Cu (f), $T_4$: NPK + Mn (f) + Cu (f), $T_5$: NPK + $N_{50}$ + Mn (f), $T_6$: NPK + $N_{50}$ + Cu (f) and $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Three foliar sprays of $ZnSO_4$. $7H_2O$ and $FeSO_4$. $7H_2O$ were done for experiment I and three foliar sprays of 0.5% $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4$. $5H_2O$ were done for experiment II separately at mid-boot, pre-milk and dough stages and elevated dose of N as top-dressing @ 50 kg/ha at 80 DAS was applied. In the experiment I and II, among varieties, PBW 550 recorded the highest yield components and qualitative improvement in grain physico-chemical characters (except Phenol Reaction Score and β Carotene), which were significantly better than PBW 621 and HD 2967 during both years of study. In the experiment I, treatments of nutrient management improved growth and yield-attributing characters, grain and straw yield, highest N content, Zn and Fe concentration and uptake in grain, straw and crop were recorded during both years of study for treatment $T_8$: NPK + Zn (s) + $N_{50}$ + Zn (f) for which grain yield increased to (55.85, 56.63 q/ha) by (54.67, 70.94 %) from control (36.11, 33.07 q/ha). Grain Zn concentration increased by (56.47, 62.81%) from (23.64, 22.48 µg/g) of control to (36.99, 36.60 µg/g) for $T_8$ : NPK + Zn (s) + $N_{50}$ + Zn (f). Grain Fe concentration increased by (38.71, 19.33 %) from (31.31, 30.67 µg/g) in control to (43.43, 43.04 µg/g) in $T_8$. In the experiment II, grain yield increased by (85.1, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) for best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Grain Mn concentration increased by (46.57, 52.32 %) from (25.62, 25.25 µg/g) control to (37.55, 38.46 µg/g) in treatment $T_7$. Grain Cu concentration increased by (74.11, 94.65 %) from (3.40, 2.99 µg/g) in control to (5.92, 5.82 µg/g) in treatment $T_7$.

**Key words:** Agronomic biofortification, Productivity, Bread wheat, Nitrogen, Zinc, Iron. Copper, Manganese

**Signature of Major Advisor** **Signature of the student**

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## ਸਾਰ-ਅੰਸ਼

ਅਜੋਕੀ ਖੋਜ, ਜਿਸਦਾ ਵਿਸ਼ਾ ''ਫ਼ਸਲੀ-ਪ੍ਰਬੰਧ ਰਾਹੀਂ ਕਣਕ ਦੇ ਦਾਣਿਆਂ ਦੇ ਖੁਰਾਕੀ ਤੱਤਾਂ ਅਤੇ ਕਿਸਮਾਂ ਦੀ ਉਤਪਾਦਕਤਾ ਵਿੱਚ ਵਾਧਾ'' ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ ਲੁਧਿਆਣਾ ਵਿਖੇ ਹਾੜ੍ਹੀ 2011-12 ਅਤੇ 2012-13 ਦੌਰਾਨ ਸਮੇ ਸਿਰ ਬੀਜੀ ਜਾਣ ਵਾਲੀ ਅਤੇ ਸੇਜੂ ਹਾਲਤਾਂ ਵਿੱਚ ਭੱਲ ਰੇਤਲੀ ਜ਼ਮੀਨ ਵਿੱਚ ਕੀਤੀ ਗਈ । ਇਸ ਜ਼ਮੀਨ ਦੀ ਮਿੱਟੀ ਦਾ ਖਾਰੀ ਅੰਗ ਸਧਾਰਨ, ਲੂਣਾਂ ਦੀ ਮਾਤਰਾਂ ਘੱਟ, ਉਪਲਬਧ ਨਾਈਟ੍ਰੋਜਨ ਘੱਟ, ਫਾਸਫੋਰਸ, ਜ਼ਿੰਕ ਅਤੇ ਪੋਟਾਸ਼ ਦੀ ਮਾਤਰਾ ਦਰਮਿਆਨੀ ਅਤੇ ਉਪਲਬਧ ਤਾਂਬੇ, ਲੋਹੇ ਅਤੇ ਮੈਗਨੀਜ ਦੀ ਮਾਤਰਾ ਘੱਟ ਸੀ । ਪਹਿਲੇ ਅਤੇ ਦੂਜੇ ਤਜਰਬੇ ਵਿੱਚ, ਵੰਡਵੇਂ ਪਲਾਟ ਨਕਸ਼ੇ ਮੁਤਾਬਕ ਮੁੱਖ ਪਲਾਟ ਵਿੱਚ ਖਾਣ ਵਾਲੀ ਕਣਕ ਦੀਆਂ ਤਿੰਨ ਕਿਸਮਾਂ ਐਚ ਡੀ 2967, ਪੀ ਬੀ ਡਬਲਿਊ 621 ਅਤੇ ਪੀ ਬੀ ਡਬਲਿਊ 550 ਬੀਜੀਆਂ ਗਈਆਂ । ਪਹਿਲੇ ਤਜਰਬੇ ਵਿੱਚ ਛੋਟੇ ਪਲਾਟਾਂ ਵਿੱਚ ਤੱਤ-ਪ੍ਰਬੰਧ ਦੀਆਂ ਨੌਂ ਟਰੀਟਮੈਂਟਾਂ ਲਗਾਈਆਂ ਗਈਆਂ । 1. ਐਨ ਪੀ ਕੇ (ਕੰਟਰੋਲ), 2. ਐਨ ਪੀ ਕੇ + ਜ਼ਿੰਕ (ਮਿੱਟੀ ਵਿੱਚ ਪਾਇਆ), 3. ਐਨ ਪੀ ਕੇ + ਜ਼ਿੰਕ ਦਾ ਸਪਰੇਅ, 4. ਐਨ ਪੀ ਕੇ + ਜ਼ਿੰਕ (ਮਿੱਟੀ ਵਿੱਚ ਪਾਇਆ) + ਜ਼ਿੰਕ ਦਾ ਸਪਰੇਅ, 5. ਐਨ ਪੀ ਕੇ + ਲੋਹੇ ਦਾ ਸਪਰੇਅ, 6. ਐਨ ਪੀ ਕੇ + ਜ਼ਿੰਕ (ਮਿੱਟੀ ਵਿੱਚ ਪਾਇਆ) + $ਐਨ_{50}$, 7. ਐਨ ਪੀ ਕੇ + $ਐਨ_{50}$ + ਜ਼ਿੰਕ ਦਾ ਸਪਰੇਅ, 8. ਐਨ ਪੀ ਕੇ + ਜ਼ਿੰਕ (ਮਿੱਟੀ ਵਿੱਚ ਪਾਇਆ) + $ਐਨ_{50}$ + ਜ਼ਿੰਕ ਦਾ ਸਪਰੇਅ, 9. ਐਨ ਪੀ ਕੇ + ਲੋਹੇ ਦਾ ਸਪਰੇਅ + $ਐਨ_{50}$ । ਦੂਜੇ ਤਜਰਬੇ ਵਿੱਚ ਛੋਟੇ ਪਲਾਟਾਂ ਵਿੱਚ ਤੱਤਾਂ ਦੀਆਂ 7 ਟਰੀਟਮੈਂਟਾਂ 1. ਐਨ ਪੀ ਕੇ (ਕੰਟਰੋਲ), 2. ਐਨ ਪੀ ਕੇ + ਮੈਂਗਨੀਜ ਦਾ ਸਪਰੇਅ, 3. ਐਨ ਪੀ ਕੇ + ਤਾਂਬੇ ਦਾ ਸਪਰੇਅ, 4. ਐਨ ਪੀ ਕੇ + ਮੈਂਗਨੀਜ ਦਾ ਸਪਰੇਅ + ਤਾਂਬੇ ਦਾ ਸਪਰੇਅ, 5. ਐਨ ਪੀ ਕੇ + $ਐਨ_{50}$ + ਮੈਂਗਨੀਜ ਦਾ ਸਪਰੇਅ, 6. ਐਨ ਪੀ ਕੇ + $ਐਨ_{50}$ + ਤਾਂਬੇ ਦਾ ਸਪਰੇਅ, 7. ਐਨ ਪੀ ਕੇ + $ਐਨ_{50}$ + ਮੈਂ ਗਨੀਜ ਅਤੇ ਤਾਂਬੇ ਦਾ ਸਪਰੇਅ ਕੀਤਾ ਗਿਆ । ਪਹਿਲੇ ਤਜਰਬੇ ਵਿੱਚ 0.5٪ ਜ਼ਿੰਕ ਅਤੇ ਫੈਰਸ ਸਲਫੇਟ ਦੀਆਂ ਅਤੇ ਦੂਜੇ ਤਜਰਬੇ ਵਿੱਚ 0.5 ٪ ਮੈਂਗਨੀਜ ਤੇ 0.1 ٪ ਕਾਪਰ ਸਲਫੇਟ ਦੀਆਂ ਤਿੰਨ ਸਪਰੇਆਂ ਕਣਕ ਤੇ ਮੱਧ ਬਗੋਲੇ ਵਾਲੀ, ਦੋਧੇ ਵਾਲੀ ਅਤੇ ਦਾਣਾ ਚਿੱਥਣ ਤੇ ਆਟਾ ਬਣਨ ਵਾਲੀ ਅਵਸਥਾ ਤੇ ਕੀਤੀਆਂ ਗਈਆਂ । ਨਾਈਟ੍ਰੋਜਨ ਦਾ 50 ਕਿੱਲੋ/ਹੈਕਟੇਅਰ ਦੇ ਹਿਸਾਬ ਨਾਲ ਬਿਜਾਈ ਤੋਂ 80 ਦਿਨ ਬਾਅਦ ਛੱਟਾ ਦਿੱਤਾ ਗਿਆ । ਦੋਵੇ ਸਾਲਾਂ ਵਿੱਚ, ਪਹਿਲੇ ਅਤੇ ਦੂਜੇ ਤਜਰਬੇ ਵਿੱਚ, ਪੀ ਬੀ ਡਬਲਿਊ 550 ਕਿਸਮ ਦੇ ਸਭ ਤੋ ਵੱਧ ਝਾੜ ਦੇਣ ਵਾਲੇ ਹਿੱਸਿਆਂ ਅਤੇ ਦਾਣਿਆਂ ਦੀ ਕੁਆਲਟੀ ਪੱਖਂ ਸੁਧਾਰ ਆਇਆ ਜੋ ਕਿ ਐਚ.ਡੀ 2967 ਤੇ ਪੀ ਬੀ ਡਬਲਿਊ 621 ਨਾਲੋਂ ਕਾਫੀ ਜਿਆਦਾ ਸੀ । ਪਹਿਲੇ ਤਜਰਬੇ ਵਿੱਚ, ਖੁਰਾਕੀ ਤੱਤਾਂ ਦੀਆਂ ਟਰੀਟਮੈਂਟਾਂ ਨੇ ਕਣਕ ਦੇ ਫਸਲ ਦੇ ਝਾੜ, ਨਾਈਟ੍ਰੋਜਨ, ਜ਼ਿੰਕ ਅਤੇ ਲੋਹੇ ਦੀ ਦਾਣਿਆਂ, ਤੂੜੀ ਅਤੇ ਫ਼ਸਲ ਵਿੱਚ ਮਾਤਰਾਂ ਨੂੰ ਦੋਵੇਂ ਸਾਲਾ ਵਿੱਚ ਵਧਾਇਆ। ਅੱਠਵੀਂ ਟਰੀਟਮੈਂਟ ($ਟੀ_8$) ਨੇ ਪਹਿਲੇ ਤਜਰਬੇ ਵਿੱਚ ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਵਿੱਚ ਕੰਟਰੋਲ ਪਲਾਟ (36.11, 33.07 ਕਵਿੰ/ਹੈਕ) ਦੇ ਮੁਕਾਬਲੇ $ਟੀ_8$ (55.85, 56.53 ਕਵਿੰ/ਹੈਕ) ਵਿੱਚ (54.67, 70.94٪) ਦਾ ਵਾਧਾ ਹੋਇਆ । ਦਾਣਿਆਂ ਵਿੱਚ ਜ਼ਿੰਕ ਦੀ ਮਾਤਰਾਂ ਕੰਟਰੋਲ ਪਲਾਟ (31.31, 30.67 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਦੇ ਮੁਕਾਬਲੇ $ਟੀ_8$ ਦੇ ਪਲਾਟ ਵਿੱਚ (43.43, 43.04 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਦਾ (56.47, 62.81٪) ਦਾ ਵਾਧਾ ਹੋਇਆ । ਦਾਣਿਆਂ ਵਿੱਚ ਲੋਹੇ ਦੀ ਮਾਤਰਾਂ ਕੰਟਰੋਲ ਪਲਾਟ (31.31, 30.67 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਦੇ ਮੁਕਾਬਲੇ $ਟੀ_8$ ਦੇ ਪਲਾਟ ਵਿੱਚ (43.43, 43.04 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਦਾ (38.71, 19.33٪) ਰਾਹੀਂ ਵਾਧਾ ਹੋਇਆ । ਦੂਜੇ ਤਜਰਬੇ ਵਿੱਚ ਦਾਣਿਆ ਦੇ ਝਾੜ ਵਿੱਚ ਕੰਟਰੋਲ ਪਲਾਟ (29.25, 32.51 ਕਵਿੰ/ਹੈਕ) ਦੇ ਮੁਕਾਬਲੇ $ਟੀ_7$ (54.15, 53.71 ਕਵਿੰ/ਹੈਕ) ਵਿੱਚ (85.10, 65.21٪) ਦਾ ਵਾਧਾ ਹੋਇਆ । ਦਾਣਿਆਂ ਵਿੱਚ ਮੈਂਗਨੀਜ ਦੀ ਮਾਤਰਾਂ ਕੰਟਰੋਲ ਪਲਾਟ (25.62, 25.25 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਦੇ ਮੁਕਾਬਲੇ $ਟੀ_7$ (37.55, 38.46 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਵਿੱਚ (46.57, 52.32٪) ਦਾ ਵਾਧਾ ਹੋਇਆ । ਦਾਣਿਆਂ ਵਿੱਚ ਤਾਂਬੇ ਦੀ ਮਾਤਰਾਂ ਕੰਟਰੋਲ ਪਲਾਟ (3.40, 2.99 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਦੇ ਮੁਕਾਬਲੇ $ਟੀ_7$ (5.92, 5.82 ਮਾਈਕਰੋ ਗ੍ਰਾਮ/ਗ੍ਰਾਮ) ਵਿੱਚ (74.11, 94.65٪) ਦਾ ਵਾਧਾ ਹੋਇਆ।

**ਮੁੱਖ ਲਫ਼ਜ਼:** ਫ਼ਸਲੀ-ਪ੍ਰਬੰਧ ਰਾਹੀਂ ਕਣਕ ਦੇ ਦਾਣਿਆਂ ਦੇ ਖੁਰਾਕੀ ਤੱਤਾਂ ਵਿੱਚ ਵਾਧਾ, ਉਤਪਾਦਕਤਾਂ, ਕਣਕ, ਨਾਈਟ੍ਰੋਜਨ, ਜ਼ਿੰਕ, ਲੋਹਾ, ਤਾਂਬਾ, ਮੈਂਗਨੀਜ

**ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਦਸਤਖ਼ਤ** **ਵਿਦਿਆਰਥੀ ਦੇ ਦਸਤਖ਼ਤ**

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## CHAPTER 1

## GENERAL INTRODUCTION

Wheat is the most widely cultivated crop which provides food and nutrition to two-third population of the world. India ranks second in wheat production in the world next to China. Wheat is the second staple food crop of India after rice. India has a total production of 95.91 million tonnes which is 12 % of the world food production from 31.34 million hectares of land with productivity of 30.61 q/ha during *rabi* 2012-13 (Anonymous 2014). It was grown on an area of 3.51 million ha in Punjab state with production of 16.59 million tonnes and grain yield of 47.2 q/ha during *rabi* 2012-13 (Anonymous 2014).

A number of wheat varieties have been developed in the past and introduced in the rice-wheat cropping system in the Indo-Gangetic plains (IGP), which has helped in enhancing food grain production substantially thereby reducing starvation and protein malnutrition. An estimated nine million hectares in the IGP is planted under rice-wheat crop rotation (Kataki *et al* 2001b).

Soil micronutrient deficiency is one of the several factors limiting rice and wheat yields in the IGP (Nayyar *et al* 2001; Kataki *et al* 2001a). Intensive mining of minerals by crops have caused greater depletion of micronutrient reserves from the soil causing deficiencies of micronutrients. According to an estimate, wheat crop removes 66-209 g Zn, 232-1219 g Fe, 141-330 g Mn and 34-50 g Cu for 2 tonnes of wheat grains. Based on micronutrient analysis of soil samples across IGP revealed 45, 8, 5 and 3 % soils were deficient in Zn, Fe, Mn and Cu (Singh 2004). As much as 48, 12, 5 and 4 % soils in India are deficient in Zn, Fe, Mn and Cu respectively (Narwal *et al* 2010). Whereas in Punjab state 22,12,11 and 2 % soils are deficient in Zn, Fe, Mn and Cu (Benbi *et al* 2011).These deficiencies cause hidden hunger, lower yields, crop failures and poor accumulation of trace elements into edible plant-parts/grains and poor nutrition to human beings. For instance, despite advances in breeding for uptake efficiency or mobilization to the grain, wheat grain zinc concentration is limited by Zn availability in the soil (Ortiz-Monasterio *et al* 2011; Annexure IX).

Micronutrient malnutrition is a global health problem affecting more than 3 billion people world-wide (Cakmak *et al* 2010). Among those, Zn and Fe deficiencies are the most prevalent ones. About 44 % children under five years of age are zinc deficient in India (Kapil and Jain 2011). About 66 and 85 % women and children are iron-anaemic in Punjab and India respectively (Singh 2009). Deficiencies of Zn and Fe cause serious human health complications such as stunting, infections, impaired brain functions, poor mental-development, weak babies and anaemia (Fraga 2005). Low dietary-intake is the main cause of microelement deficiencies in

humans (White and Broadley, 2009; Cakmak *et al* 2010). Zn is also essential in human body as a co-factor for more than 200 enzymatic reactions which are vital for growth, development, immune function and resistance to infections (Fischers and Black 2004).

Among the staple food crops, wheat is the most important cereal in a number of developing countries with respect to its contribution to daily calorie intake (Cakmak 2008). Wheat is inherently very low in the bioavailability of Zn, Fe, Mn and Cu. Under severely Zn deficient soils, the Zn concentration of wheat grains may be as low as 10 mg/kg whereas the human requirement is 40-60 mg/kg and the current situation for world is 10-30 mg/kg (Cakmak *et al* 2010a).The availability range of Zn, Fe, Cu and Mn in the wheat varieties in India varies from 20-30, 28-51, 2-5 and 24-30 mg/kg respectively (Anonymous, 2011). The recommended dietary allowance (RDA) of micronutrients for young adults in India ranges from 12 mg/day for Zn, 17-21 mg/day for Fe, 2 to 3 mg/day for Cu and 5-7 mg/day for Mn (Anonymous 2009).These nutrients are mostly present in the wheat bran which is usually removed during flour-making and normally white flour (endosperm) is consumed as bread (Annexure VI).

By optimizing the timing and the solute concentration of foliar Zn application, wheat Zn concentration could be further increased not only in wheat grains but also in the endosperm (Cakmak *et al* 2010 b and Zhang *et al* 2010). Normally, an adult person consumes about 250-300 g of wheat flour as bread. The concentration of micronutrients in most of the wheat varieties needs enhancement to fulfill the daily human requirement. The average protein content of bread wheat varieties varies from 11-12 % which can be increased further for higher quality of bread making by selecting efficient cultivars and effective nitrogen management. A grain protein content of 13 % or more is required including elastic gluten (protein) to produce a good loaf of bread (Singh 2001).

Latest reports indicate that improved nitrogen status as biofortification strategy may increase the Zn and Fe concentration in the whole grain and endosperm of wheat. Experiment on wheat showed that increasing soil or foliar application of N at critical growth stages was highly effective in improving root uptake, shoot and grain accumulation of Zn and Fe (Aciksoz *et al* 2011, Kutman *et al* 2011). For example, under high N supply around 60 % of total shoot Fe was allocated to seeds while in case of low N supply this value was around 38 % (Kutman *et al* 2011). Among the interventions for tackling mineral malnutrition, biofortification of staple food crops with micronutrients through genetic and/or agronomic tools is probably the most sustainable and cost-effective strategy (White *et al* 2002, Cakmak 2008).

Under Punjab conditions, insufficient work has been done so far to study the role of N in relation to soil/foliar application of micronutrients and their influences on the wheat quality and

productivity at the critical phenological phases during the pre and post-anthesis periods. The impact of improved N nutrition on the transport of Zn, Fe, Cu and Mn to grain during the ontogenesis of new wheat varieties need to be studied. Recently, it has been reported that grain concentration of Zn and Fe can be increased by enhancing the N supply. Zn and N applications have a synergistic effect on grain Zn concentration of wheat (Kutman *et al* 2010; Shi *et al* 2010).

Nitrogen nutrition of plant appears to be a critical component for an effective biofortification of food crops with Zn and Fe due to their role in physiological and molecular mechanisms which are under the influence of nutritional status of N (Kutman *et al* 2010). Breeding new plant genotypes for high grain concentration (genetic biofortification) of microelements is the long-term strategy to address the global problem of mineral malnutrition. A rapid and complementary approach is required for agronomic biofortification of food crops with micronutrients.

Biofortification is the process of increasing the natural content of nutrients in edible part of crop plants (Welch 2005).The supply of minerals to the developing cereal grain originates from two sources: first as a result of direct uptake from the soil(Annexure II, III and IV) and second from the remobilization of stored minerals in leaves as they senesce during the stage of grain filling. Concentration or density is the amount of nutrient per unit of grain dry weight, which is more important measure of micronutrient supply in grain than micronutrient content (the total amount of nutrient per seed or plant). Concentration of Zn and Fe in cereal grain increase with an increase in Zn or Fe fertilizer additions at critical growth stages (Marschner 1995). The amounts of Zn or Fe fertilizers in excess of what is required for achieving optimum yield may result in increased micronutrient concentration of grain. The process of mineral-enrichment takes place well above the sufficiency level of a nutrient with-in the crop plant (Annexure VIII).

Plants are capable of absorbing soluble compounds and gases through leaves (Annexure V). Application of foliar spray implies that nutrient applied will be absorbed from the point of application (leaves) to the point of utilization (growing tissue). An export of nutrient from leaves and transport within the stem occurs in phloem (Annexure III), while transport in the stem may occur in either phloem or xylem (Rengel *et al* 1999). Soil/foliar application of nitrogenous and micronutrient fertilizers at specific and critical growth stages of wheat may contribute towards mineral enrichment of grain (Annexure I) and yield enhancement by improving their availability because some mineral like Fe and Mn are involved in photosynthetic electron transport (Marschner *et al* 1996).The most effective method for increasing grain zinc is the soil+foliar application method which may result in an about 3 fold increase in grain Zn concentration (Cakmak *et al* 2010a).

The timing of foliar spray of micronutrients is an important factor determining its effectiveness in increasing grain enrichment of microelements. For instance, large increases in zinc grain concentration are most likely when foliar Zn fertilizers are applied to wheat at a late growth stage (Annexure X). Ozturk *et al* (2006) studied changes in grain Zn concentration in wheat and found that the highest concentration of grain Zn occurs during the milk stage of grain development. Late season foliar application of Zn increased the concentration in the starchy endosperm by up to 3 fold. Since the concentration of phytate in the starchy endosperm (i.e. white flour) is very low or even not measurable (Pomeranz 1988), such an increase in Zn implies a positive effect on the use of grain for human nutrition (Annexure VI and VII). The increased Zn in the starchy endosperm resulting from foliar application should also be highly bioavailable due to the low phytate content (Velu *et al* 2013).

Adequate research has not been done on agronomic biofortification of new wheat varieties using fertilization strategies for improvement in yield and quality in the Punjab state. We can tackle the current global challenge of mineral malnutrition which is avoidable with biofortification (Anonymous 2004 and 2008). Agronomic biofortification through fertilizer approaches could complement the existing breeding approach; for instance, foliar application of Zn fertilizer can increase grain Zn above the breeding target set by nutritionists (Velu *et al* 2013).

Considering all these above stated views, present study was undertaken with the following objectives:

1) To study the impact of nutrient management on growth, productivity and quality of bread wheat varieties.
2) To study the agronomic biofortification of wheat grains by management of nitrogen, zinc, iron, manganese and copper.

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**CHAPTER 2**

# REVIEW OF LITERATURE

The literature related to the study on **"Agronomic biofotification and enhancement of productivity in bread wheat (*Triticum aestivum* L.) varieties."** has been reviewed under the following heads:

**2.1 Growth and yield performance of varieties**

**2.2 Performance of varieties in terms of micronutrients accumulation in grain**

**2.3 Interaction of wheat varieties and increase in nitrogen levels**

**2.4 Effect of nitrogen on growth, yield, biofortification and grain quality**

**2.5 Effect of Zn on growth, yield, biofortification and grain quality**

**2.6 Effect of Fe on growth, yield and biofortification**

**2.7 Effect of Mn on growth, yield and biofortification**

**2.8 Effect of Cu on growth, yield and biofortification**

**2.9 Cumulative effect of Zn, Fe, Mn and Cu on growth, yield, biofortification and grain quality**

## 2.1 Growth and yield performance of varieties

As seed develops on the parent plant, concentration of nutrients in seed is dependent on soil type, nutrient availability, crop species, season and cultivars (Ascher 1994). Different genotypes may differ in phenological behavior and interaction with different management practices due to genetic variation. Taller varieties are generally less responsive to fertilizer application and give lesser yields than the dwarf ones. The varieties have been found to differ in their efficiency to accumulate dry matter and yield attributing characters. The development of semi-dwarf wheat cultivars which resist lodging more than conventional taller varieties have improved wheat yields by allowing greater efficient use of nitrogen fertilizer. In research trials at PAU Ludhiana, it was observed that the bread wheat genotypes (WH 542 and HD 2329) recorded significantly higher dry matter production, leaf area index and effective tillers than *durum* wheat (Singh *et al* 1996).

Khan *et al* (2007) in Peshawar concluded that all the characters were negatively affected as a result of late sowing yet the genotypes CT 01217, CT 01222 and CT 01085 with grain yield of 47.45, 43.34 and 43.34 q/ha respectively performed well with respect to harvest index (40.5, 31.0 and 36.5 %) and medium plant height character (89, 92 and 91 cm) as compared to those of the best check line (Bakhtawar 92) which is an indication that some bread wheat genotypes among existing germplasm may have in built resistance/tolerance against terminal heat stress

under late planting condition. Kariuki *et al* (2007) conducted an experiment at Southern Great Plains and concluded that the variety 2137 and OK 101 had significantly higher yield than Jagalene and Jagger wheat cultivar. Singh *et al* (2007) conducted an experiment in Karnal and reported that the varieties PBW 343, NW 1012, DL 788-2 and RAJ 3765 had higher root and shoot biomass for absorption of moisture and nutrients as compared to WH 147, HUW 234, HD 2285, HD 2402, WH 542, UP 2338, PBW 373, NW 1014, UP 2425, HUW 468 and Raj 3777. Singh *et al* (2007) conducted an experiment at Faizabad (Uttar Pradesh) and concluded that the variety Halna had highest grain yield followed by variety K 8962, DW B14, NW 1076 and NW 1014. Tayyar (2007) conducted an experiment in North-Western Turkey and reported that Romanian bread wheat variety Joseph gave significantly higher yield and higher quality characters than local varieties. Zhang *et al* (2008) reported that increasing the basic seedling and fertilizer application properly in proper time could improve its yield, yield attributes and quality parameters in Yannong 19 wheat variety.

Mujahid *et al* (2008) conducted the experiment in Faisalabad (Pakistan) and reported that the variety Seher 06 gave significantly higher grain yield (10 %) than Inqilab 91. Pandey *et al* (2008) from Pusa (Bihar) reported that the variety HP 1744 recorded significantly higher yield attributes, grain yield, straw yield, N uptake, net returns and B:C ratio than the variety UP 262.

Ranjbar *et al* (2010*)* conducted an experiment in Iran and concluded that the variety Sistan produced highest grain yield than variety Verinak. Kumar *et al* (2010) reported that the varieties WH 1022 and PBW 343 gave significant significantly higher number of spikes/$m^2$ and biological yield than WH 711, whereas the grain yield was significantly higher in cultivar WH 1022. Kant *et al* (2010) conducted an experiment in Almora (Uttarakhand) and reported that the variety VL Gehun 892 gave significantly higher grain yield and variety PBW 226 characterized for earliness and high grain weight which has early maturity (143 days) and higher average productivity/day (10.2 q/ha/day) making it a suitable for late sowing in northern hills of India. As genotypes vary widely, nitrogen has got differential response (Singh *et al* 2010).

**2.2 Performance of varieties in terms of micronutrients accumulation in grain**

Torun *et al* (2000) observed that among the 164 wheat genotypes zinc efficiency varied from 0.33 to 0.77. The differences in tolerance to zinc deficiency were totally independent of Zn shoot concentration but showed a close relationship to the total Zn content of shoot. Khoshgoftarmanesh *et al* (2004) studied the Zn efficieny of five wheat cultivars on saline calcareous soil at Iran and reported that variation was found among wheat cultivars in relation to grain yield, straw yield and Zn use efficiency. The cultivar Cross was most efficient and Dur-3 was most inefficient for Zn use efficiency whereas cultivars Kavir, Falat and Rushan were

intermediate in Zn use efficiency. Zn concentration and uptake were significantly higher in the Zn efficient cultivar cross. Oury *et al* (2006) studied the genetic variability and stability of grain Mg, Zn and Fe concentrations in different genotypes and observed that Zn concentrations ranged from 15 to 35 ppm but increased to 43 ppm in some genotypes. Variation in Zn was due to the effect of the genotype and high G x E interactions whereas Fe concentration ranged from 20-60 ppm.

Joshi *et al* (2010) studied the effect of genotype × environment interaction in eastern Gangetic plains of India for variation in Fe and Zn concentrations of wheat grains and reported that micronutrient density in grain is highly variable for different genotypes sown at different locations. Velu *et al* (2011) in a multilocation study reported that the magnitude of variability for grain Zn and Fe concentrations in 600 wheat accessions of diverse origin. Grain Zn concentrations among the accessions ranged from 16.85 to 60.77 mg/kg and Fe concentrations ranged from 26.26 to 68.78 mg/kg. The highest levels of Zn and Fe concentrations were observed in Chinese spring bread wheat accessions HONG DUAN MANG and accession from Spain ANDALUCIA 344 respectively. There was a significant and positive correlation betweenZn and Fe concentrations ($r = 0.81$; $p < 0.01$), indicating simultaneous improvement of both the micronutrients.

**2.3 Interaction of wheat varieties and increase in N levels**

Singh *et al* (2008) conducted an experiment at Lucknow on sandy loam soils and reported that salt-tolerant variety KRL 19 gave 13 % higher yield over KRL 14 with 150 kg N/ha. Maximum agronomic response was found in cultivar CBR 13 with 120 kg N/ha and it decreased with increase in nitrogen level but in traditional cultivar Bejhari response to nitrogen reduced drastically with increasing levels of nitrogen.

Bakht *et al* (2010) reported from Peshawar (Pakistan) that maximum nitrogen concentration in straw and grain was recorded in the variety Saleem 2000 when fertilized with 150 kg N/ha (2/3rd soil + 1/3rd foliar) compared with Uqab 2000 and Pirsabak 2004. Iqbal *et al* (2010) reported from Faisalabad that the highest grain yield (59.09 q/ha) was recorded in Sehar 2006 with the application of 120 kg N/ha followed by Sehar 2006 with 180 kg N/ha (50.47 q/ha). Minimum grain yield (25.07 q/ha) was recorded in Shafaq 2006 without any dose of nitrogen. Aynehband *et al* (2010) from Iran that modern wheat variety Dena had the best grain yield because of greatest dry matter translocation efficiency and contribution of pre-anthesis assimilates to grain with higher nitrogen use and translocation at high N application.

**2.4 Effect of nitrogen on growth, yield and biofortfication**

Nitrogen is the most important component of plant and constitutes about 1-5 % by weight. The constitution of atmospheric nitrogen is 78 % but it is mainly available to plants from

soil. Nitrogen is mostly absorbed by plants as nitrates ($NO_3^-$) and $NH^+_4$ ions and its availability mainly depends upon many biological processes and addition of fertilizers. The nitrogen absorbed within plants is assimilated into various amino acids that constitute various proteins which provide the framework for choloroplast, mitochondria and other plant structures in which biochemical reactions take place. N is an integral part of pyroll ring in chlorophyll, which is primary absorber of light energy needed for photosynthesis (Havlin *et al* 2010). It plays an important role in plant life for achievement of optimum vegetative growth, dry matter accumulation and partitioning of proteins in the sink/grains. The effect of N has been studied under following sub-heads:

**2.4.1 Effect of dose and timing of nitrogen on growth and yield**

Delayed N application at the late stage $Z_{31}$ (Zadoks 31$^{st}$ growth stage, when internodel distance between first and second node still less than 2 cm) of wheat (Annexure X), results in higher N recoveries which often translate into higher yields, higher protein concentrations in the grain (Fischer *et al* 1993; Ortiz-Monsterio *et al* 1994), less lodging and lower incidence of the karnal bunt (*Tilletia indica*) (Hobbs *et al* 1988).

Fischer (1993) reported that extra N supplement of 60 kg/ha at boot stage boosted grain yield significantly. In wheat crop subjected to nitrogen deficiency before anthesis, kernel number is reduced and is controlled by dry matter or N accumulation in spikes (Demotes-Mainard *et al* 1999).

Goswami (2007) reported from U.P. that grain yield of wheat was significantly higher at dose of 100 kg N/ha as compared to 75 kg N/ha and control. Agarwal *et al* (2007) from Bihar reported that application of recommended dose of 100 kg N/ha, 50 kg $P_2O_5$ /ha and 25 kg $K_2O$/ha increased the grain yield to an extent of 71.6 % over 50 % NPK and was statistically at par with 75 % NPK level. Al-Rawashdeh and Abdel-Ghani (2008) from Jordan concluded that single N application (40 kg N/ha) was relatively higher than split-N application in improving dry matter accumulation in vegetative parts at anthesis and maturity stages, grain and biological yield and N translocation efficiency.

Kaur and Pannu (2008) reported from Haryana that increase in splits and foliar application of nitrogen increased the duration of maturity, reproductive phase and grain growth phase which resulted in significantly higher grain and biological yield. Pandey *et al* (2008) from Bihar with available 216 kg N/ha in soil, reported that tillers per metre row length, grain, straw yield, N-uptake and net returns increased significantly with successive increase in nitrogen level upto 120 kg N/ha. However, they reported that B : C ratio was increased up to 80 kg N/ha only. Vukovic *et al* (2008) conducted an experiment at Croatia and concluded that best N use

efficiency was recorded at level of 100 kg N/ha which is considered as rational application regarding nitrogen emissions into environment. Experiments conducted in different parts of India revealed that high yielding varieties of wheat respond significantly to N application upto 120 kg N/ha with occasional responses observed up to rate of 150 kg N/ha under intensive cropping.

Kumar *et al* (2009) reported from Haryana that 100 % recommended dose of 60 kg N/ha, 30 kg $P_2O_5$/ha and 20 kg $K_2O$/ha gave significantly higher wheat grain yield. Madan and Munjal (2009) conducted an experiment in Hisar and reported that grain yield was significantly higher at 125 kg N/ha and 112.5 kg N/ha as compared to control. Mankotia and Thakur (2009) reported from Malan (H.P.) that application of 100 % (120 kg N + 26.2 kg $P_2O_5$ + 24.5 kg $K_2O$/ha) and 150 % of recommended fertilizer increased wheat productivity by 5.3 (19.6 %) and 10.7 (39.5 %) q/ha respectively as compared to 50 % of recommended dose. Yadav and Kumar (2009) conducted an experiment in U.P. and reported that the response to dose of 150 kg N/ha was less in wheat as compared to rice. Singh *et al* (2009) reported from New Delhi that bread wheat responded significantly higher to 100 kg N/ha. Jing *et al* (2009) reported from China that nitrogen uptake by wheat increased with increasing N rate while agronomic nitrogen use efficiency declined at rates exceeding 150 kg N/ha. The highest grain yield of wheat was obtained at 300 kg N/ha.

Jan *et al* (2010) conducted an experiment and reported that split N application is recommended for improved biological yield whereas for improved quality of grains the delayed application of N at boot stage is preferable in agro-climatic condition of Peshawar. Madani *et al* (2010) observed that additional N supply at anthesis had no significant effect on the total above ground biomass, but increased grain yield through more allocation of dry matter to grains.

**2.4.2 Effect of nitrogen on biofortification**

The N nutritional status of plants may greatly influence the uptake, transport, re-translocation and grain deposition of Zn, Fe and Cu .The trafficking of Zn and Fe cations from the rhizosphere into grains is dependent on various proteins, amino acids and peptides. Transporter proteins such as Zn regulated transporter (ZIP)/Fe regulated transporter like proteins are involved in the root uptake, xylem to phloem exchange, phloem loading, unloading and grain deposition of Zn and Fe (Waters *et al* 2006; Haydon and Cobbett 2007; Borg *et al* 2009; Cui *et al* 2010; Palmer and Guerinot 2009).

In recent literature, it has been suggested that grain protein is a sink for Zn and Fe (Persson *et al* 2009; Cakmak *et al* 2010; Kutman *et al* 2010). Enhanced N status within crop plants contributes to release of Fe-mobilising compounds from roots (phytosiderophores), enhances root uptake and transport of Fe via increasing pool of transporter proteins, facilitates

translocation and phloem transport of Fe via chelation with nitrogenous compounds and improves seed deposition of Fe by increasing amount of proteins in seeds (Cakmak *et al* 2010). Genes controlling the concentration of protein, Zn and Fe are possibly co-segregating. The presence of strong positive correlation between grain Zn, Fe and protein within the grain tissue and the co-localization of the relevant loci on the same chromosome indicate close links between physiological mechanisms result in grain accumulation of Zn, Fe and protein. High N can increase the grain Zn and Fe concentration by enhancing the grain protein concentration and thereby increasing the sink strength in grains for Zn and Fe. Significant positive co-relations between seed protein, Zn and Fe concentrations have been documented in various studies (Morgounov *et al* 2007, Paleg *et al* 2008, and Zhao *et al* 2009).

Shi *et al* (2010) studied the effect of long-term N fertilization rates (0, 130 and 300 kg/ha) on micronutrient density in grain of winter wheat in China and reported that the N fertilization increased the concentration of the micronutrients (Zn, Fe and Cu) and protein in wheat grain.

**2.4.3 Effect of nitrogen on grain quality**

The nitrogen dose may affect the quality of the bread wheat varieties especially protein. The grain protein is basically a genetic trait, but it can be manipulated through nitrogen application at elevated levels at critical growth stages. It has been seen that addition of nitrogen at adequate time could boost both grain yield and protein content (Ottoman *et al* 2000). It has been observed further that application of nitrogen fertilizer during vegetative phase affected the grain yield but application during reproductive phase affected protein content (Strong 1982, Whest and Cassman 1982).

The grain appearance score depends upon grain-size, shape, luster and colour. Grains are uniform in shape, bold in size, glossy in luster and amber in color due to higher protein and beta-carotene content of grains. Hardness and vitreousness are mechanical and optical properties respectively.Vitreous endosperms have high gliadin content which cause higher adehesion of the protein matrix on starch granules during kernel dessication causing compact endosperm shape (Samson *et al* 2005). Ottesen *et al* (2007) reported from North Dakota that increasing level of nitrogen significantly increased the protein content of wheat.

Suek and Podolska (2008) reported from Poland that the best grain quality parameters were found for a dose of 180 kg N/ha applied three times during the vegetation period (60 kg before sowing + 60 kg in shooting phase + 60 kg in heading phase). Podolska (2008) reported from Poland that nitrogen fertilization applied at a dose of 120 kg N/ha three times during the growing period of winter wheat caused an increase in protein, gluten content and sedimentation

value compared with two times. Stankowski *et al* (2008) reported from Poland that increasing the nitrogen dose from 90 to 150 kg/ha significantly increase the protein content. Gluten content increased after 180 kg/ha of nitrogen application.

Rutkowska (2009) reported from U.S.A. that wheat plants supplied with 0.9 g N/pot enhanced grain yield by 28 % and gluten content by 62 % and plant supplied with 2.9 g N/pot by 27 % and 13 %, respectively. Singh *et al* (2009) reported from Ludhiana (Punjab) that application of 150 kg N/ha increased the total N uptake by wheat crop in sandy loam and silt loam soils over 0, 90 and 120 kg N/ha. Brennan and Bolland (2009) conducted an experiment in Australia and concluded that increased nitrogen resulted in increased protein concentration in wheat grains.

Kaur *et al* (2010) reported from Bathinda (Punjab) that there was a significant increase in nitrogen content in grain as well as in straw under nitrogen scheduling [68 kg N at sowing + 75 kg N at irrigation + 7 kg N (3 % urea spray) at anthesis] as compared to control. Arora *et al* (2010) reported from Ludhiana (Punjab) that N uptake significantly higher at application of 150 kg N/ha over 120 kg N/ha. Meena (2010) reported from Bundi (Rajasthan) that split-application of N (40:40:40) kg/ha produced significantly higher test weight over 2 splits (0:80:40) kg/ha but statistically at par with 3 splits (20:50:50) and (60:60:0) kg/ha. Kharub and Chander (2010) conducted an experiment in Haryana and reported that three or four splits of nitrogen resulted in significantly higher total protein yield of wheat as compared to 2 splits of nitrogen.

Ooro *et al* (2011) reported from Kenya that wheat flour protein content and grain nitrogen increased significantly in response to N rate. Coventry *et al* (2011) conducted an experiment in Haryana and reported that the application of extra N fertilizer with non rice-wheat rotations produced no additional grain yield with an increase in N fertilizer beyond 150 kg N/ha, only protein content and N content was increased incrementally. Mattas *et al* (2011) reported from Ludhiana (Punjab) that the N uptake and N content increased significantly with increasing level of N application from 120 to 180 kg N/ha in *durum* wheat varieties.

**2.5 Effect of zinc on growth, yield, biofortification and grain quality**

The normal concentration range of Zn is 25 to 150 mg/kg in plants. Zinc toxicity occurs when the Zn leaf concentration exceeds 400 mg/kg. Plant roots absorb Zn as $Zn^{+2}$ ions as the component of synthetic and natural complexes. Zn complexes can also enter the plant system through leaves. Zn is transported symplastically across the root to the xylem although a substantial fraction may traverse the root and reach the xylem via the apoplast (White *et al* 2002; Broadley *et al* 2007).

Zn deficient plants show decrease in membrane integrity, succeptibility to heat stress, decreased synthesis of carbohydrates, decreased cytochrome and nucleotide synthesis, decreased

auxin synthesis, decreased chlorophyll synthesis and inhibition of Zn enzymes (Marschner 1995, Marschner *et al* 1996 and Pathmanabhan *et al* 2007).

Based on a series of reports, the average concentration of Zn in whole grain of wheat in various countries is between 20-35 mg/kg (Rengel *et al* 1999; Cakmak *et al* 2004). The reported Zn concentrations are too low to meet daily human requirement. For a measurable biological impact on human health the concentration of Zn in whole wheat grains need to be increased at least by 10 mg/kg (Pfiffer and Mcclafferty 2007). Zn effect can be studied under following sub-heads:

**2.5.1 Effect of zinc on growth and yield**

Applying Zn fertilizers to wheat grown in fields in central Anatolia, Turkey improved productivity (Yilmaz *et al* 1997). Plants emerging from seeds with low Zn have poor seedling vigour and weak establishment in field on Zn-deficient soils (Yilmaz *et al* 1998).

Ranjbar and Bahmaniar (2007) observed the effect of soil and foliar application of Zn fertilizers on growth and yield of bread wheat cultivars and showed that using Zn caused increasing effect on plant height, total dry matter, number of tillers and grain yield.

Shivay *et al* (2008) conducted field experiments at the IARI, New Delhi and reported that application of Zn in the form of 0.5 to 2 % of Zn enriched urea significantly increased yield attributes, grain and straw yield, Zn concentrations in the grain and straw and Zn uptake. $ZnSO_4$ and ZnO were equally effective in increasing the grain yield of wheat. The agronomic and crop recovery efficiency of applied Zn decreased as the level of Zn enrichment was increased from 0.5 to 2 %. Based on these results the application of 0.5 to 1 % Zn enrichment of urea with $ZnSO_4$ or 1 % Zn enrichment with ZnO was recommended. Zn enrichment of urea with $ZnSO_4$ gave significantly higher agronomic efficiency then ZnO.

It was reported by Narwal *et al*, (2010) that maximum increase in grain yield was achieved when the recommended dose of $ZnSO_4$@ 25 kg/ha was applied as soil application and 0.5 % solution of $ZnSO_4$ as foliar spray. Habib (2009) and Imitiaz *et al* (2010) also reported similar results of Zn nutrition in wheat. Hussain *et al* (2012) reported from Pakistan that soil Zn application at high rate increased grain yield by 29 %.

Dhaliwal *et al* (2012) coducted experiments at Ludhiana and Hoshiarpur in sandy loam and loamy sand soils respectively and reported that various plant parameters of wheat variety PBW 550 such as plant height, no of tillers/$m^2$ increaed with soil application of $ZnSO_4 7H_2O$@62.5kg/ha and foliar spray of Zn chelates which significantly increased grain yield.

Interactive effects of Zn and N were investigated by Jan *et al* (2013) on wheat at Peshawar. The experiment consisted of four levels of N (0, 50, 100 and 150 kg/ha) and six levels

of Zn (0, 3, 6, 9, 12 and 15 kg/ha). Application of N @150 kg/ha and Zn@15kg/ha resulted in the improved growth, highest yield components and highest grain yield (4044 kg/ha) and straw yield (5067 kg/ha) of wheat.

**2.5.2 Effect of zinc on biofortification and grain quality**

Applying Zn fertilizers to wheat grown in fields in central Anatolia, Turkey improved grain Zn concentration also (Yilmaz *et al* 1997). An increased Zn transport from leaves into seeds can be achieved by foliar application of Zn, particularly under environmental stress conditions (e.g. drought) and on potentially deficient Zn soils (Yilmaz *et al* 1997; Welch 1999). Ranjbar and Bahmaniar (2007) reported the effects of soil and foliar application of Zn fertilizers in terms of increase in grain Zn and Fe content, higher increase in percentage of protein in Tajan cultivars than Nye 60.

Peck *et al* (2008) studied the effect of Zn nutrition on the protein composition of flour in bread wheat at Australia and reported that foliar Zn application doubled grain Zn concentration and reduced the proportion of Gliadin and SDS-unextractable polymeric protein and increased the proportion of SDS-extractable polymeric protein. The results indicated that Zn nutrition can alter protein composition in interaction with grain filling temperature. It was reported by Cakmak (2008) at Turkey that the most effective method for increasing Zn in grain was soil and foliar application that resulted in about 3.5 fold increase in the grain Zn concentration.

The increase in Zn percentage through foliar application over non-foliar application was more in Zn deficient soils as compared to Zn sufficient soils (Ram *et al* 2011). Zhang *et al* (2011) studied the effect of Zn biofortification of wheat through fertilizer application on different locations of China and results showed that foliar Zn application was much more effective than soil Zn application in enrichment of wheat grain with Zn as compared to no foliar Zn application. Foliar application of 0.4 % $ZnSO_4.7H_2O$ application resulted in grain Zn with 58 % increase in whole grain Zn, 76 % increase in wheat flour Zn and up to 50 % decrease in the molar ratio of phytic acid to Zn in flour. Wen *et al* (2011) concluded from his experiments at China that foliar Zn application at the early grain development stage increased grain Zn concentration and decreased the phytic acid concentration and the phytic acid to Zn molar ratio thereby improving the bioavailability in wheat grown on potentially Zn-deficient calcareous soil.

Hussain *et al* (2012) reported from Pakistan that soil Zn application combined with foliar spray during the grain development stage increased the Zn concentration in grain by 95 % and whole-grain estimated bioavailability by 74 %. Zou *et al* (2012) studied the biofortification of wheat with Zn through Zn fertilization in seven countries of the world and reported that foliar Zn application alone or in combination with soil Zn application resulted in significant increase in

grain Zn concentrations in all locations and in all local cultivars used in those countries on an average, the grain Zn concentrations increased from 27.4 mg/kg to 48.0 mg/kg by foliar Zn application.

Dhaliwal *et al* (2012) also reported that foliar application of {1-hydroxyethane 1,1-diphosphonic acid, concentrated and liquid formulations of chelates} Zn-HEDP (C)@2g/liter and Zn-HEDP (L) @3g/liter increased the grain concentration by 29.2 % over control. For Zn-HEDP (L) 3g/liter was more effective for Zn enrichment but for Zn-HEDP (C)@2g/liter significantly higher uptake of Zn was observed.

**2.6 Effect of iron on growth, yield and biofortification**

The sufficiency range of Fe in plant tissues is normally between 50 and 250 mg/kg. Iron is absorbed by plant roots as $Fe^{2+}$, $Fe^{3+}$ and as organically complexed iron. The $Fe^{2+}$ form is more mobile and available for incorporation into bio-molecular structure. Iron is a structural component of cytochromes, hematin and ferrichrome. These substances are involved in redox reactions in respiration and photosynthesis (Marschner *et al* 1996 and Pathmanabhan *et al* 2007).

Ziaeian and Malakouti (2001) observed that Fe application increased concentration and total uptake of Fe in wheat grains. Mohammad *et al* (2009) studied the response of wheat plants to Zn, Fe and Mn applications, uptake and their accumulation in wheat grains. Foliar application of Fe increased its concentration in grain by 21 %. Habib (2009) reported that foliar application of Fe and Zn at tillering and heading stage increased Fe and Zn concentration from 84.93 to 139.6 and 12.17 to 20.27 mg/kg respectively, compared with control and consequently increased grain yield. Similar results have been reported by Yilmaz *et al* (1997) and Seilsepour (2007).

Dhaliwal *et al* (2009) observed that four foliar sprays of $FeSO_4.7H_2O$ @0.5 % at different stages of wheat starting from maximum tillering, flower initiation, milk and dough stage resulted in significant increase in Fe concentration in wheat grains from 13.1 to 30.3 % in comparison to control. A recent report by Cakmak (2010) shows that biofortification of cereals with Fe and Zn is possible through fertilization strategy. Latest evidence in literature indicates that nitrogen status of plants has a positive influence on grain accumulation of Fe (Kutman *et al* 2010).

Aciksoz *et al* (2011) also observed that the plant N status is an important factor in enrichment of cereal grains with Fe. Molecular evidences also proved that remobilization of N and Fe from vegetative tissue and translocation into seed is governed by the same molecular mechanism establishing a positive correlation between grain Fe and N concentration.

## 2.7 Effect of manganese on growth, yield and biofortification

The normal concentration of Mn in plants typically ranges from 20 to 500 mg/kg. Plant parts having Mn concentration below 15 to 20 mg/kg are considered deficient. Mn is absorbed by plants as $Mn^{2+}$ in molecular combination with certain natural and synthetic complexing agents. Like Fe, Mn is relatively immobile element and deficiency symptoms usually show up first in the younger leaves. Mn is involved in evolution of oxygen in photosynthesis. It also takes part in redox reactions, decarboxylation and hydrolysis reactions. Mn is needed for activity of many enzymatic reactions in the citric acid cycle and influences auxin levels in plants. Mn is required for enzyme activation in electron transport and disease-resistance (Marschner *et al* 1996, Pathmanabhan *et al* 2007). The dietry sources of Mn are whole grain, rice, tea and nuts. Mn is toxic in excess causing a Perkinson like syndrome in brain (Kapil and Jain 2011).

The Mn content in seed and straw can be increased significantly by applying 0.5 % $MnSO_4$ to the generative tissues (Ascher 1994). As per the latest findings of Narwal *et al* ( 2010), soil and foliar applied Mn (along with Fe and Zn) significantly increased tillering, ear-length, number of grains/tiller, thousand grain weight, grain yield and crop biomass as well as their concentrations in the seed and straw (Grunner and Alloway 1985; Alloway 1986). Zeidan *et al* (2010) reported that the wheat plants treated with Mn gave the highest thousand grain weight compared with other treatments.

Dhaliwal *et al* (2011) conducted an experiment in loamy sand soil on six wheat cultivars at PAU, Ludhiana and reported that four foliar sprays of 0.5 % $MnSO_4$ at maximum tillering, flower-initiation, milk and dough stages significantly increased the wheat yield varying from 1.44-5.15 %. Enrichment of Mn in wheat grains with foliar sprays was 24-28 %.

## 2.8 Role of copper on growth, yield and biofortification

Copper (Cu) is absorbed by plants as $Cu^{2+}$ ion as part of either natural or synthetic-organic complexes. Its normal concentration in plant tissue ranges from 5 to 200 mg/kg. Cu is unique in its involvement in enzymes and cannot be replaced by any other metal ion Cu is involved in various cell and plant growth functions as a constituent of cytochrome oxidase and component of many enzymes and promotes synthesis of vitamin A (Marschner *et al* 1996, Pathmanabhan *et al* 2007).

There is about 80 mg of Cu in the adult human body with maximum concentration in liver and brain. Cu as a co-factor of lysyl oxidase is required in the cross-linking of collagen and elastine. Cu deficiency in human causes inhibition of bone growth and osteoporosis (Kapil and Jain 2011).

Amounts of exchangeable metals in soil are related to their concentration in soil solution as soil pH affects exchangeable Fe, Mn, Cu and Zn similarly. The activity (consequent bioavailability) of Zn, Mn and Cu decreases 100 fold and of Fe by 1000 fold for each unit decrease in soil pH (Lindsay 1991). The phyto-availability of Cu in many agricultural soils is low and Cu supplied to the soil through basal application becomes rapidly unavailable to the plants (Gupta 1979). Nevertheless, Cu concentration in cereals, fruits and vegetables can be increased by Cu fertilization (Gupta 1979; Rengel *et al* 1999; Bunzl *et al* 2001).

Dhaliwal *et al* (2011) conducted an experiment in loamy sand soil on six wheat cultivars at PAU, Ludhiana and reported that four foliar sprays of Cu @ 0.2 % applied at maximum tillering, flower initiation, milk and dough stages of six wheat cultivars viz. PBW 550, PBW 502, PBW 343, PDW 291, PDW 274 and PDW 233 increased the concentration of Cu in wheat grains by 2.17-6.67 %. Foliar sprays of Cu @ 0.2 % increased the growth parameters and wheat yield varying from 0.19-1.47 %.

## 2.9 Cumulative effect of Zn, Fe, Mn and Cu on growth, yield, biofortification and grain quality

### 2.9.1 Cumulative effect of Zn, Fe, Mn and Cu on growth and yield

The impact of mineral nutrients stored in seed increases crop growth rate and productivity through the direct involvement of mineral nutrients in synthesis, partitioning and utilization of photosynthates. An improvement in crop-biomass and grain yield was observed by Bedi and Kataki (1999) in all the wheat varieties, when a cocktail of micronutrients' solution was sprayed at various crop stages. The biomass increase was maximum when sprayed at ear emergence and anthesis stage. This increase was maximum and significant in PBW 154 and WH 542. A field experiment conducted in Pakistan by Asad and Rafique (2000) on wheat to study the combined effect of Zn, Fe, Cu and Mn increased wheat dry matter, straw yield and grain yield significantly over control.

Zeidan *et al* (2010) showed that application of Zn, Fe and Mn significantly increased grain yield and yield components of wheat in comparison to control. Foliar application of Zn, surpassed other treatments followed by Mn and Fe. Results of a study conducted in 815 irrigated wheat growing regions of Iran to evaluate the effects of micronutrients showed an increase of 4 to 11 % in wheat grain yield by the addition of each micronutrient (Fe, Cu, Zn and B) or a combination of Fe, Cu, Zn and B to NPK fertilizer (Malakouti 2000). Dhaliwal *et al* (2011) conducted an experiment in loamy sand soil on six wheat cultivars at PAU, Ludhiana and reported that foliar sprays of Mn @ 0.5 % and Cu @ 0.2 % significantly increased the wheat yield varying from 1.44-5.15 % and 0.19-1.47 % respectively.

### 2.9.2 Cumulative effect of Zn, Fe, Mn and Cu on biofortification and grain quality

The improvement in grain quality parameters may be attributed to the role of microelements in enhanced accumulation of assimilates in the grain during grain filling stage and thus the resulting seeds had greater individual masses (Baskin *et al* 1998 and Fenner 1992). Foliar application of Zn directly relates to flag leaves' significantly higher Zn concentration followed by Mn and Fe. These results are in accordance with the findings of Yilmaz *et al* (1997).

Bedi and Kataki (1999) studied at PAU, Ludhiana that spraying the crop at four growth stages with a micronutrient solution containing Zn, Cu, Mn and Fe increased seed micronutrient content at harvest by 63, 60, 22 and 48 % of Zn, Fe, Mn and Cu respectively. Mohammad and Mohammad (2009) observed in Iran that foliar application of 0.5 % $ZnSO_4$ increased Zn and Fe conc. in wheat grains by 99 % and 8 % respectively. Foliar application of 1 % $FeSO_4$ resulted in 21 % increase in Fe concentration and 13 % increase in Zn conc. in wheat grains. Foliar application of 0.5 % $MnSO_4$ resulted in 7 % increase in Mn concentration in grains. The highest number of grains were produced in soil application of $ZnSO_4$ @ 80 kg/ha.

Mahmed *et al* (2010) studied the effect of foliar spray with uniconazol and micronutrients on wheat and observed that 0.1 % foliar spray of $MnSO_4$ and $FeSO_4$ at tillering and ear-emergence stage increased photosynthetic pigments, yield, NPK, Mn and Fe conc. in grain greatly. Zeidan *et al* (2010) reported that the foliar applications of micronutrients enhanced plant absorption of N, P, Zn, Fe and Mn thereby increasing the concentrations in the flag leaves of wheat crop. Zeidan *et al* (2010) further observed that foliar application of microelements significantly increased protein, Fe, Mn and Zn concentration in grain of wheat as compared to control treatments.

Dhaliwal *et al* (2011) conducted an experiment in loamy sand soil on six wheat cultivars at PAU, Ludhiana and reported that foliar sprays of 0.5 % Mn and 0.2 % Cu caused enrichment of Mn and Cu in wheat grains by 24-28 % and 2.17-6.67 % respectively.

It has been concluded from above review of literature that the varietal performance may change according to the genetic constitution and the agro-climatic conditions in the ambience. The concentration of Fe and Zn in wheat grain varies from genotype to genotype which interact with environment to cause the variation in micronutrient density in grain. Nitrogen dose changes with the shift in geographic location of wheat producing regions. The modern dwarf wheat varieties respond well to increased N levels as compared to traditional tall varieties. Nitrogen governs the translocation of micronutrients within plants and their localization in the wheat grain. Nitrogen applied at a higher dose and in the late reproductive stage has a positive effect on the quality parameters of grain. Zinc alone or in combination with N significantly improves growth

and grain yield of wheat. Soil application of $ZnSO_4.7H_2O$ @62.5kg/ha and foliar application of zinc chelates such as Zn-HEDP (C) @ 2g/liter and Zn-HEDP (L) @ 3g liter and 0.4-0.5 % solution of $ZnSO_4$ improves growth, grain yield, grain concentration and quality of wheat grain. Foliar application of Fe is effective than soil application in increasing yield and grain concentration in seed and straw of wheat. Foliar spray of Mn @0.5 % can effectively increase the yield and Mn concentration in grain. Overall, increased dose of nitrogen alone or in combination with soil/foliar applications of Zn (0.5 %), Fe (0.5-1 %), Mn (0.1-0.5 %) and Cu (0.2 %) in the late reproductive phases enhance growth, yield, mineral density and overall quality of the wheat grains.

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**CHAPTER 3**

## ACCEPTED/PUBLISHED/SUBMITTED RESEARCH ARTICLES

| SR. NO. | TITLE | STATUS | JOURNAL | NAAS RATING |
|---|---|---|---|---|
| 1. | Impact of varieties and nutrient application of nitrogen, copper and manganese on yield attributes and yield of wheat (*Triticum aestivum* L.).<br>**Pardeep Kumar, R S Uppal, H Ram and S Bedi** | Accepted | **Indian Journal of Fertilizers, (IJF)** Published by Fertilizer association of India (FAI), New Delhi | 3.78 |
| 2. | Grain quality of bread wheat as affected by varieties and nutrient application of nitrogen, manganese and copper<br>**Pardeep Kumar, R S Uppal, H Ram and H Kaur** | Published | **Indian Journal of Fertilizers, (IJF)** Published by Fertilizer association of India (FAI), New Delhi | 3.78 |
| 3. | Agronomic biofortification, nutrient uptake and productivity of wheat (*Triticum aestivum* L.) as influenced by fertilization strategies.<br>**Pardeep Kumar, R S Uppal, H Ram, J S Manchanda** | Submitted | **Indian Journal of Fertilizers, (IJF)** Published by Fertilizer association of India (FAI), New Delhi | 3.78 |

THE FERTILISER ASSOCIATION OF INDIA

ENSURING FOOD SECURITY

FAI/AGS/9.1
5th September 2014

Pardeep Kumar,
Department of Agronomy,
Punjab Agricultural University,
Ludhiana-141 004,
Punjab, India

**Sub: Acceptance of Research Paper**

Dear Sir,

This is to inform you that the paper entitled "Impact of varieties and nutrient application of nitrogen, copper and manganese on yield attributes and yield of wheat(*Triticum aestivum* L.)" by Pardeep Kumar, R.S.Uppal, H. Ram and S. Bedi has been accepted for publication in Indian Journal of Fertilisers. The paper will be published in any of the forthcoming issues of IJF.

Thanking You,

Yours faithfully,

Dr. R.K. Tewatia
Addl. Director (Agricultural Sciences)

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THE FERTILISER ASSOCIATION OF INDIA

ENSURING FOOD SECURITY

FAI/AGS/9.1
4th September 2014

Pardeep Kumar,
Department of Agronomy,
Punjab Agricultural University,
Ludhiana-141 004,
Punjab, India

**Sub: Acceptance of Research Paper**

Dear Sir,

This is to inform you that the paper entitled "Grain quality of bread wheat as affected by varieties and nutrient application of nitrogen, manganese and copper" by Pardeep Kumar, R.S.Uppal, H. Ram and H.Kaur has been accepted for publication in Indian Journal of Fertilisers. The paper will be published in any of the forthcoming issues of IJF.

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**Acknowledgement of paper**

Sep 4 (4 days ago)

**FAI-Agricultural Sciences**

Dear Dr. Pardeep kumar,

We acknowledge with thanks the receipt of your paper entitled "Agronomic biofortification, nutrient uptake and productivity of wheat (*Triticum Aestivum* L.) as influenced by fertilization strategies." By Pardeep Kumar, R. S. Uppal, H. Ram*, and J. S. Manchanda** for publication in IJF.

Regards,

**R.K.Tewatia**

**_____**
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## 3.1 PAPER I

**Impact of varieties and nutrient application of nitrogen, copper and manganese on yield-attributes and yield of wheat (*Triticum aestivum* L.).**

**Pardeep Kumar, R S Uppal, H Ram*and S Bedi****

Department of Agronomy, *Department of Plant Breeding and Genetics, Department of Botany** Punjab Agricultural University, Ludhiana – 141004, Punjab, India

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**A field study was conducted consecutively for two years during cropping seasons of *rabi* 2011-12 and 2012-13 at Punjab Agricultural University, Ludhiana under timely-sown, irrigated conditions on loamy sand soil (*Typic Ustochrept*) testing near normal in pH, low EC, low in available N, medium in available P and K, low in available Cu and available Mn. The experiment was laid out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient treatments ($T_1$: NPK alone as control, $T_2$: NPK + Mn (f), $T_3$: NPK + Cu (f), $T_4$: NPK + Mn (f) + Cu (f), $T_5$: NPK + $N_{50}$ + Mn (f), $T_6$: NPK + $N_{50}$ + Cu (f) and $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) in the sub-plots. Three sprays of both 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4$. $5H_2O$ were done separately at mid-boot, pre-milk and dough stage. Among varieties, PBW 550 recorded the highest growth and yield components, straw and grain yield which were significantly better than varieties PBW 621 and HD 2967 during both years of study. Among the treatments of nutrient management, the best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f), which caused increased height, LAI, crop biomass, tiller count, number of fertile tillers/$m^2$, spike length, number of grains/spike, thousand grain weight culminating in enhanced straw, grain yield and improved harvest index. Grain yield increased by (85.10, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The straw yield increased by (69.37, 43.61 %) from (45.22, 52.79 q/ha) in control to (76.59, 75.81 q/ha) for $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The harvest index also significantly increased from (39.28, 38.11) in control to (41.42, 41.46) for $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 DAS and foliar applications of Mn (0.5 %) and Cu (0.2 %) in the late reproductive phases (mid-boot, pre-milk and dough) enhanced growth and productivity of the wheat.**

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Wheat is the second staple food crop of India after rice. India has a total production of 95.91 million tonnes which is 12 % of the world food production from 31.34 million hectares of land with productivity of 30.61 q/ha during *rabi* 2012-13 (2). It was grown on an area of 3.51 million ha in Punjab with production of 16.59 million tonnes and grain yield of 47.2 q/ha during *rabi* 2012-13 (2). According to an estimate, India will have to produce at least 109 million tons of wheat by 2020 AD to feed its 1.3 billion population, which might be possible by elevation of productivity up to 40 q/ha (16). Now, it is being felt among the crop scientists that the yield of wheat has reached a plateau. Still, the continuous efforts are on to increase the productivity of wheat beyond the so-called barriers.

Fertilizers have played a key role in the sustainable food grain production of our nation. The varieties have been found to differ in their efficiency to accumulate dry matter and yield attributing characters. Taller varieties like Kalyan Sona were less responsive to fertilizers and gave lesser yields than the dwarf ones. The development of semi-dwarf cultivars with *norin* blood (Mexican types) resistant to lodging than conventional taller varieties which have improved yields by allowing efficient use of fertilizers.

Micronutrients play a pivotal role in the yield improvement (30). They are needed in trace amounts but their adequate nutrient availability positively affects cell physiology that is reflected in yield as well (35, 1). It is advocated that foliar sprays of nutrient solutions at tillering, jointing and boot stages increase yield and yield components of wheat (3).

Soil/foliar application of nitrogenous and specific micronutrient fertilizers at critical growth stages of wheat may contribute towards growth and yield-enhancement by improving availability and uptake of nutrients. Nitrogen is an integral component of grain protein. Mn is involved in photosynthetic electron transport (19) and photolysis of water (the most crucial step in photosynthesis), Cu as co-factor of many essential enzymes has important roles in the growth and metabolism of plants (19). Hence, Present study was devised with the objective to study the impact of nutrient management on growth and productivity of bread wheat varieties popular among farmers such as HD 2967, PBW 621 and PBW 550 through fertilization methods.

**Material and methods**

Before sowing**,** bulk composite surface soil samples (0–15 and 15-30 cm depth) were collected from research field of the Department of Agronomy, Punjab Agricultural University, Ludhiana representing the Indo-Gangetic alluvial plains, situated at $30^0$ 56/ N latitude and $75^0$ 52/ E longitude and at an altitude of 247 meters above mean sea level. The air-dried soil was ground to pass through a 2.0-mm sieve, and a sub-sample of the sieved soil was analyzed for various mechanical and physico-chemical properties. Soil texture was loamy-sand (sand 82.30 %, silt 7.2

% and clay 10.5 %) as determined by International pippet method (25). Soil pH (7.30) was determined by pH meter of Jackson (13). Electical conductivity of the saturated soil paste was low (0.15 $dsm^{-1}$) as determined by Jackson's salt bridge method (12). Soil organic carbon (0.24 %) was low, as determined by Walkley and Black's rapid titration method (36). Plant-available Mn and Cu in the soil were low with values 3.40 and 0.18 mg $kg^{-1}$ soil, respectively, determined by DTPA method (17) from 1:2 soil-extractant ratio using DTPA-TEA buffer (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA, pH 7.3) and measured on an atomic absorption spectrophotometer (Varian-AAS FS 240 Model). Available nitrogen (34), available phosphorous (24) and available potassium (5) in the soil samples were determined by the standardized procedures.

The experiment was laid out in the split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient treatments [$T_1$ :NPK alone as control, $T_2$:NPK + Mn (f), $T_3$:NPK + Cu (f), $T_4$ : NPK + Mn (f) + Cu (f), $T_5$ :NPK + $N_{50}$ + Mn (f), $T_6$ :NPK + $N_{50}$ + Cu (f), $T_7$ : NPK + $N_{50}$ + Mn (f) + Cu (f)] in the sub-plots. Three foliar sprays each of 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4.5H_2O$ were done separately at three crucial growth stages such as mid-boot, pre-milk and dough stage. Three varieties were sown on 7 November, 2011 and 2012. Nitrogen was applied @ 125 kg/ha as urea in 3 splits (1/2 at sowing, 1/4 after first irrigation and 1/4 after second irrigation). Additional dose of nitrogen @ 50 kg/ha was applied 80 days after sowing (DAS). Phosphorous @ 62.5 kg/ha as DAP and potassium @ 30 kg/ha as MOP was applied as full basal dose before sowing. The pH of $CuSO_4.5H_2O$ spray solution was neutralized by adding a solution of quicklime (50 % of its total weight) after weighing, soaking overnight and by mixing the supernatant after decantation to make a spray solution of 200 litres per hectare. The foliar spray was done with a spray pump fitted with a flood-jet nozzle, the spray volume being enough to drench the crop. All foliar sprays contained 0.01 % (v/v) Tween as a surfactant to enhance the penetration of foliar fertilization through cuticle of leaf surface.

**Field observations**

**Emergence count:** Seedlings/meter row length were counted from two representative sites in each plot from its emergence up to one week. The results were expressed as number of seedlings/$m^2$. **Plant height:** Five plants were selected randomly to measure the height from ground level to the base of top-most fully opened leaf and at maturity up to spike tip (without awns). **Dry matter accumulation:** Above ground plant samples of a meter row length were taken at maturity from two places from the lines leaving the two border lines. The samples were first sun-dried. Afterwards, these samples were oven-dried at a temperature and kept in an oven at a temperature of 55 ± $10^0$C for 24 hrs to achieve constant weight. **No. of tillers/$m^2$:** Number of

tillers/ row length from each plot were counted at 90 and 120 DAS. **Leaf area index (LAI):** Periodic leaf area index was recorded directly by using sun scan canopy analyser. **No. of effective tillers/m$^2$:** The number of spike bearing tillers were counted from two middle rows of one metre row length in each plot at harvest and was finally expressed as effective tillers/m$^2$. **Ear length (cm):** Five representative spikes were selected randomly from each plot and their length from base to the apex (excluding awns) was measured and expressed in centimeters. Finally spike length was expressed as average length of five panicles. **No. of grains/ear:** Five ears were taken randomly from each plot, threshed, counted and averaged for number of grains/ear. **Thousand grain weight (g):** One thousand grains were counted from the harvest produce of each treatment. The sample was collected after the threshed-product sufficiently dried and brought to moisture content of 13 per cent. Their weight (g) was recorded using electronic balance and expressed in grams. **Grain yield (q/ha):** Harvested crop produce from net plot was threshed manually by beating against hard surface. The grain yield was recorded in kg /plot. **Straw yield (q/ha):** Bundle weight was taken before threshing and straw weight (kg) was recorded after deducting grain weight (kg) from the whole bundle weight (kg), which was then expressed in q/ha. **Harvest index:** Harvest index was calculated by dividing economic (grain) yield by the total biological (grain + straw) yield and then multiplied by 100 to express as percentage.

**Availability of metal cations in soil:**

Amounts of exchangeable metals in soil are related to their concentration in soil solution as soil pH affects exchangeable Mn and Cu similarly. The activity (consequent bioavailability) of Mn and Cu decreases 100 fold for each unit decrease in soil pH. The phyto-availability of Cu in many agricultural soils is low and Cu supplied to the soil as basal application becomes rapidly unavailable to the plants (10).

## Results and Discussion

### Plant height

The perusal of the data at harvest shown in Table 1. Indicates that, among varieties, the plant height of wheat varieties PBW 621 (87.6, 83.5 cm) and HD 2967 (88.7, 84.2 cm) were statistically at par in height but significantly higher than PBW 550 (76.4, 74.3 cm). All nutrient treatments had significantly more height than control. The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (89.6, 86.6 cm), which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (88.5, 84.4 cm). Further, the treatment $T_4$ was statistically at par with $T_5$: NPK + $N_{50}$ + Mn (f) (86.2, 83.5 cm) but significantly higher than $T_2$: NPK + Mn (f) (83.1, 80.4 cm) and $T_3$: NPK + Cu (f) (80.1, 75.6 cm).

The increase in plant height might be attributed to the role of N, Mn and Cu in plant growth, metabolism and higher photo-synthetic activity. Cells developed with elevated level of N tend to be large and having higher meristematic activity and formation of protoplasm which increases the plant growth (6).

**Dry matter accumulation**

Dry matter accumulation is the total accumulation of photosynthates and total nutrient uptake by the plant up to stimulated growth period. It indicates the photosynthetic-efficiency of crop. Dry biomass recorded is given in Table 1.

Among wheat varieties there was significant effect on dry matter accumulation. The variety PBW 550 (108.1, 108.8 q/ha) produced significantly lower dry matter than PBW 621 (114.3, 116.3 q/ha). The variety PBW 621 was statistically at par with variety HD 2967 (110.2, 111.7 q/ha). The differences in dry matter accumulation are due to differential increase in vegetative growth rate of these varieties.

In the treatments of nutrient management, $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (133.1, 130.6 q/ha) recorded the highest dry matter yield, which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (126.8, 125.3 q/ha), which was significantly higher than all other treatments. All nutrient treatments were significantly superior to control in height. It was reported earlier also that soil and foliar applied Mn significantly increased crop-biomass apart from role of N in boosting plant growth (23, 7).

**Leaf area index (LAI)**

LAI is an important indicator of crop growth. Higher the LAI, higher will be the PAR interception which is the source of energy for the process of photosynthesis, which accumulates more photosynthates for translocation to grains resulting in higher yield.

Table 1. shows that among the varieties, LAI differed significantly. The variety PBW 550 (3.56, 3.52) recorded significantly lower LAI than PBW 621 (3.88, 3.83). The variety PBW 621 was significantly higher than HD 2967 (3.75, 3.69) during both the years of study. This might be due to differential ability of wheat varieties in LAI and tillering habit. Moreover, PBW 550 is shy in tillering. It was reported earlier that the higher LAI was recorded in both the cultivars SH 06 and AS 02 at 90 DAS and in SH 06 at 105 DAS (11).

During both years, nutrient management treatments had significant effect on LAI. Treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (4.35, 4.27) recorded significantly higher LAI than all the treatments. The second best treatment was $T_4$ [NPK + Mn (f) + Cu (f)] (3.85, 3.82), which was significantly higher than treatments $T_1$: NPK (Control) (3.12, 2.90), $T_2$: NPK+Mn (f) (3.28, 3.24), $T_3$: NPK+Cu (f) (3.25, 3.21), $T_5$: NPK+$N_{50}$+Mn (f) (3.58, 3.54) and $T_6$: NPK+$N_{50}$+Cu (f)

(3.40, 3.36). All treatments were significantly higher than control.

It might be attributed to reason that vegetative growth resulting from higher photosynthetic activities might be affected by additional dose of N @ 50 kg/ha just before heading combined with foliar application of Mn/Cu and its synergistic effect with foliar application of Mn and Cu. It was reported earlier also that increase in N dose before anthesis can result increase in LAI by 62 % (31).

**Tiller count**

Tillering is another important factor in bread wheat. The tillering stage in wheat generally comes at 40-45 DAS which finally leads to higher ear production and yield elevation.

Table **1.** shows that the vareity PBW 621 (345, 340 tillers/$m^2$) was statistically at par with HD 2967 (340, 338 tillers/$m^2$) but significantly higher than PBW 550 (323, 320 tillers/$m^2$) at 90 DAS. At 120 DAS, both varieties PBW 621(327, 323 tillers/$m^2$) and HD 2967 (323, 320 tillers/$m^2$) were statistically at par with each other but significantly higher than PBW 550 (307, 305 tillers/$m^2$).

The maximum tillers were produced at 90 DAS with the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (394, 390 tillers/$m^2$) which were significantly higher than all other treatments such as $T_1$: NPK (Control) (325, 320 tillers/$m^2$), $T_2$: NPK+Mn(f) (345, 340 tillers/$m^2$), $T_3$: NPK+Cu(f) (337, 332 tillers/$m^2$), $T_4$ [NPK+Mn(f)+Cu(f)] (385, 380 tillers/$m^2$), $T_5$: NPK+$N_{50}$+Mn(f) (375, 371 tillers/$m^2$) and $T_6$: NPK+$N_{50}$+Cu (f) (367, 362 tillers/$m^2$). This may be attributed to the synergistic effect of Mn/Cu and N on tillering. Improved supply of nutrients induced higher tillering as compared to lower N status. It was also reported that N application had tremendous effect on formation and survival of tillers (26). Tiller count for all the treatments including maximum tiller number for $T_7$ (375, 371 tillers/$m^{2)}$ decreased 120 DAS in comparison to tiller count at 90 DAS.

The increase in tiller number with the increased micronutrient (Mn and Cu) and nitrogen availability is attributed to the rapid conversion of carbohydrates in to proteins and consequently increased the number and size of growing cells which ultimately resulted in increase in number of tillers (32).

**YIELD ATTRIBUTES**

**Effective tillers at harvest**

The number of effective tillers/$m^2$ are the main yield component. The data on the effective tillers/$m^2$ are presented in Table 2**.** During both years, PBW 621 (319, 312 tillers/$m^2$) produced the highest number of effective tillers, which was significantly higher than PBW 550 (300, 295 tillers/$m^2$) but statistically at par with HD 2967 (315, 310 tillers/$m^2$).

All the treatments of nutrient management were significantly higher than control. The maximum number of effective tillers were produced with the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (364, 355 tillers/$m^2$) which were significantly higher than all other treatments such as $T_1$: NPK (Control) (284, 275 tillers/$m^2$), $T_2$: NPK+Mn(f) (315, 312 tillers/$m^2$), $T_3$: NPK+Cu(f) (308, 305 tillers/$m^2$), $T_4$ [NPK+Mn(f)+Cu(f)] (355, 349 tillers/$m^2$), $T_5$: NPK+$N_{50}$+Mn(f) (345, 340 tillers/$m^2$) and $T_6$: NPK+$N_{50}$+Cu (f) (337, 335 tillers/$m^2$). The increased effective tillers/$m^2$ with higher dose of N on tillering through cytokinin-synthesis resulted into more number of effective tillers/$m^2$ (8, 33). It has been reported earlier that semi-dwarf varieties due to exploitation of more assimilates to the ear during pre-flowering period result in higher number of fertile tillers/$m^2$ and more fertile florets (6, 20). Mn being part of photosynthetic machinery also contributed to enhanced photo-synthesis (19).

**Ear length**

Ear length indicates the number of spikelets which in turn affects the number of grains. Much of the ear development depends upon the availability of carbohydrates when there is competition with strong sinks like tillers, leaf and stem (29).

The data presented in Table 2 shows that, the variety PBW 550 (10.4, 10.5 cm) produced the highest ear length which was significantly higher than PBW 621 (9.9, 9.3 cm) and HD 2967 (9.1, 8.8 cm). PBW 621 and HD 2967 were statistically at par with each other for ear length.

All the treatments of nutrient management were significantly higher than control (8.7, 8.4 cm). The treatment $T_7$: NPK + + $N_{50}$ + Mn (f) + Cu (f) was the best one (10.7, 10.4 cm) which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (10.4, 10.3 cm). The treatment $T_4$ was significantly higher than all other treatments such as $T_2$: NPK+Mn(f) (9.1, 9.7 cm), $T_3$: NPK+Cu(f) (9.2, 9.1 cm), $T_5$: NPK+$N_{50}$+Mn(f) (10.1, 9.8 cm) and $T_6$: NPK+$N_{50}$+Cu (f) (9.6, 9. cm). The increase in ear-head length has been reported earlier up to 160 kg N/ha (27).

**Number of grains/ear**

The number of grains/ear is an important component of grain yield. Grains/ear is the product of spikelets/ear and grains/spikelets. The sink capacity of grain is the product of number of grains set and growth characteristics of individual grains (29). The data of number of grains/ear are presented in Table 2**.**

Among the varieties, the variety PBW 550 (46.7, 44.6) produced the highest number of grains/ear which was significantly higher than PBW 621 (42.9, 41.2) and HD 2967 (37.7, 36.3). The varieties PBW 621 and HD 2967 were statistically at par with each other for number of grains/ear.

All the treatments of nutrient management were significantly higher than control (41.0, 39.3). The best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (44.6, 42.3) was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (43.7, 42.0). Further, the treatment $T_4$ was significantly higher than all other treatments such as $T_2$: NPK+Mn (f) (41.9, 40.4), $T_3$: NPK+Cu (f) (41.2, 39.9), $T_5$: NPK+$N_{50}$+Mn (f) (42.9, 41.5) and $T_6$: NPK+$N_{50}$+Cu (f) (41.8, 39.9). Adequate availability of N might have increased the grains/ear by preventing the degradation of spikelets at the time of grain development. The increased number of spikelets led to incremental increases in spike length. Similar results were reported earlier also (28).

All Interaction effects were significant (Table 5). The interaction values indicated that the highest values of number of grains/ear were recorded for the combination of treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (49.5, 47.2) and variety PBW 550. $T_7$ was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) for varieties HD 2967 and PBW 621 but differed significantly under variety PBW 550. The lowest number of grains/ear were recorded for the combination of treatment control and variety HD 2967 (35.9, 34.7), which was statistically inferior to combination of treatment control and variety PBW 621 values (41.1, 40.0). The control plots sown with variety PBW 550 (45.3, 43.1) were significantly superior to control plots sown with variety PBW 621 (45.3, 43.1).

**Thousand grain weight (g)**

Thousand grain weight is a reliable index of seed development, plumpness, grain quality and crop yield. The data is presented in Table 2. The variety PBW 550 (43.5, 42.6 g) produced the highest thousand grain weight, which was significantly higher than variety PBW 621 (40.6, 39.6 g) and HD 2967 (40.5, 38.7 g). Similar results related to the thousand grain weight were reported earlier (14).

All the treatments of nutrient management were significantly higher than control (37.8, 35.6 g). The best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (45.0, 44.7 g) was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (43.9, 43.7 g). Further, $T_4$ was significantly higher than all other treatments except $T_5$: NPK + $N_{50}$ + Mn (f) (42.8, 41.1 g). This may be attributed to the synergistic effect of N and foliar application of Mn/Cu which might have incrased the thousand grain weight. Similar results were reported earlier (4).

**Grain yield (q/ha)**

Crop productivity is the rate at which a crop accumulates biomass which depends primarily on the rate of photosynthesis. The yield of wheat is composed of yield components such as effective tillers/$m^2$, number of grains/ear, spike length and thousand grain weight (TGW). Though TGW does exert an influence on grain yield but its effect is lower than spike

length and number of grains/spike (22). The data on grain yield is presented in Table 3, Fig 3.

All the three varieties were statistically at par with each other for grain yield. Similar results were reported by others (9). All the treatments of nutrient management were significantly higher than control (29.25, 32.51 q/ha). $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) was the best treatment (54.15, 53.71 q/ha), which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (52.65, 51.73 q/ha). The treatment $T_4$ was statistically at par with the treatment $T_5$: NPK + $N_{50}$ + Mn (f) (48.70, 47.43 q/ha). Further, the treatment $T_5$ was significantly higher than other treatments such as $T_2$: NPK+Mn (f) (47.57, 44.93 q/ha), $T_3$: NPK+Cu (f) (42.53, 43.54 q/ha) and $T_6$: NPK+$N_{50}$+Cu (f) (45.14, 45.20 q/ha). The significant effect of foliar application of Mn and Cu is apparently visible with comparison of $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f) with NPK control. Grain yield increased by (62.63, 38.20 %) from (29.25, 32.51 q/ha) in control to (47.57, 44.93 q/ha) for $T_2$: NPK + Mn (f). Grain yield increased by (45.40, 33.93 %) from (29.25, 32.51 q/ha) in control to (42.53, 43.54 q/ha) for $T_3$: NPK + Cu (f). Grain yield increased by (85.10, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) for best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f).

Mn promoted evolution of oxygen in photosynthesis, enzyme activation in electron transport and disease-resistance (19) thereby enhancing phtosynthates, their increased translocation to grain and finally increased yield in the treatments $T_2$, $T_4$, $T_5$ and $T_7$ (Table 2.). Copper involved in various cell and plant growth functions as a constituent of cytochrome oxidase and component of many enzymes and promoted synthesis of vitamin A (19) resulting in increased photosynthesis, photosynthates and their translocation into grain thereby increasing crop yield in the treatments $T_3$, $T_4$, $T_6$ and $T_7$ (Table 2.).

The increase in grain yield was due to the cumulative effect of increase in all the yield-attributing components such as effective tillers/$m^2$, number of grains/ear, spike length and thousand grain weight (Table 2.). Additional N supply before heading and foliar application of Mn and Cu might have increased grain yield through more allocation of dry matter to grains. Similar results were reported earlier also (4, 7, 15, 18).

**Straw yield (q/ha)**

Straw yield also makes important contribution to the overall crop value.The straw yield is presented in Table 3. All the three varieties were statistically at par with each other for straw yield.

All the treatments of nutrient management, were significantly higher than control (45.22, 52.79 q/ha). $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment (76.59, 75.81 q/ha), which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (72.13, 76.45 q/ha). The treatment

$T_4$: NPK+Mn (f)+Cu (f) was significantly superior to $T_3$: NPK+Cu (f) (58.56, 67.17 q/ha) by (23.17, 13.82 %) and $T_6$: NPK+$N_{50}$+Cu (f) (60.89, 67.04 q/ha) by (25.78, 14.04 %). The significant effect of foliar application of Mn and Cu is apparently visible with comparison of $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f) with NPK control. Straw yield increased by (14.05, 3.10 %) from (58.56, 67.17 q/ha) in control to (66.79, 69.22 q/ha) for $T_2$: NPK + Mn (f). Straw yield increased by (29.50, 27.24 %) from (45.22, 52.79 q/ha) in control to (58.56, 67.17 q/ha) for $T_3$: NPK + Cu (f). Straw yield has increased by (68.37, 43.61 %) from (45.22, 52.79 q/ha) in control to (76.59, 75.81 q/ha) for best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f).

The increase in straw yield was due to the cumulative effect of increase in all the straw yield attributing indices such as plant height, dry matter accumulation, LAI and number of tillers (Table 1.). The increase in straw yield may be due to the combined effect of Cu and Mn increased wheat dry matter, straw yield and grain yield significantly over control. Similar results were reported earlier by others (3).

**Harvest index**

Harvest index is an important parameter indicating the efficiency in partitioning of dry matter to the economic part of crop. Higher harvest index, higher is the economic return of the crop. The data regarding harvest index have been presented in Table 3.

Wheat varieties had significant effect on harvest index. The variety PBW 550 (43.05, 42.84) had significantly higher harvest index in comparison to varieties HD 2967 (42.02, 39.14) and PBW 621 (39.72, 38.63). The variety PBW 621 recorded lowest harvest index. These results are in line with as reported earlier (21).

All the treatments of nutrient management were significantly higher as compared to control (39.28, 38.11) during both the years. The treatment $T_5$ : NPK + $N_{50}$ + Mn (f) (42.25, 39.85) was statistically at par for harvest index with $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (41.42, 41.46). This might be due to favorable effects of increased availability of nitrogen, Mn and Cu on growth and yield-attributing characters which helped in the translocation of photosynthates in to grain and increased the grain yield (3).

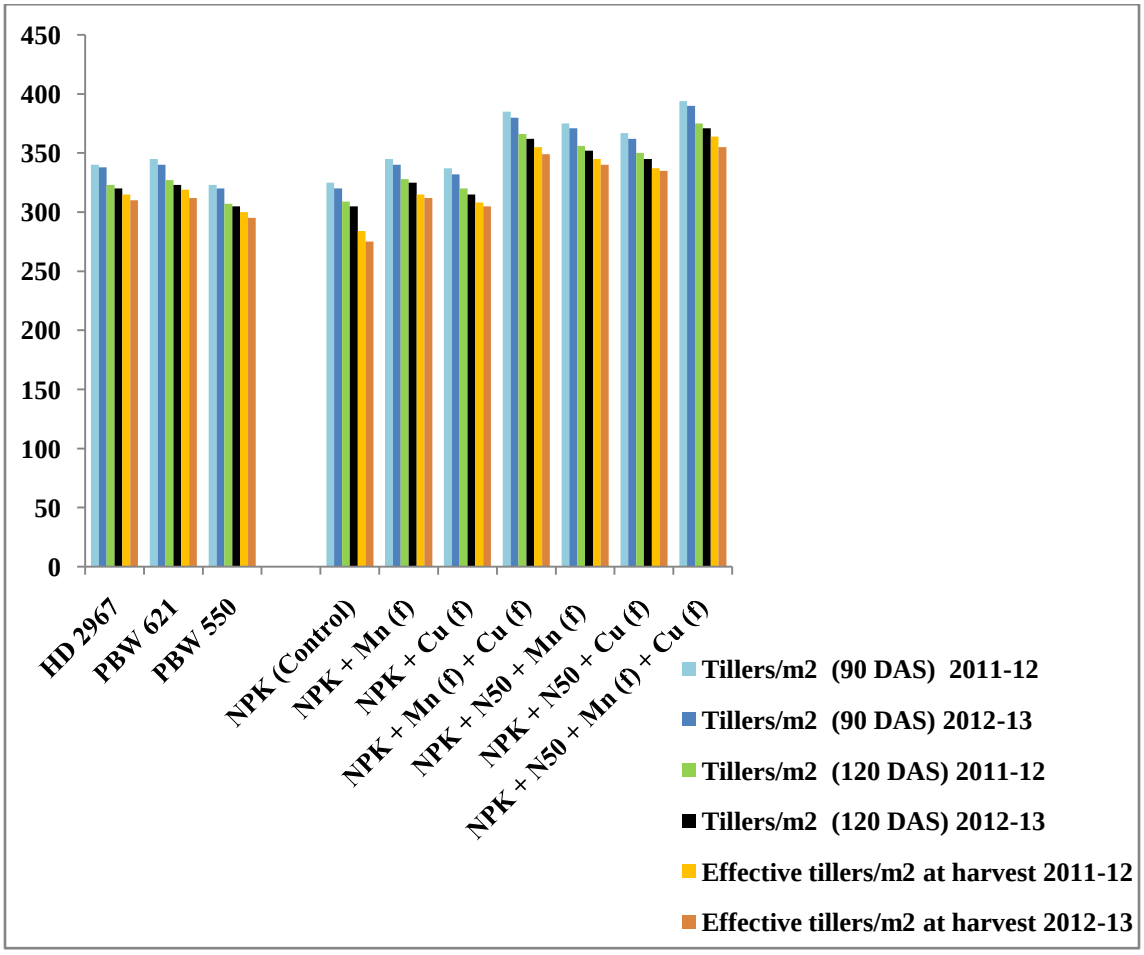



**Fig 1. Tillers/$m^2$ and effective tillers/$m^2$ as influenced by varieties and nutrient management**

| Table 1. Effect of varieties and nutrient management on growth chracteristics of bread wheat | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Plant height (cm)** | | **Dry matter accumulation (q/ha)** | | **Leaf area index (LAI)** | | **Tillers/m$^2$** | | | |
| | | | | | | | **90 DAS** | | **120 DAS** | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| **Varieties (V)** | | | | | | | | | | |
| $V_1$: HD 2967 | 87.6 | 83.5 | 110.2 | 111.7 | 3.75 | 3.69 | 340 | 338 | 323 | 320 |
| $V_2$: PBW 621 | 88.7 | 84.2 | 114.3 | 116.3 | 3.88 | 3.83 | 345 | 340 | 327 | 323 |
| $V_3$: PBW 550 | 76.4 | 74.3 | 108.1 | 108.8 | 3.56 | 3.52 | 323 | 320 | 307 | 305 |
| **LSD (p=0.05)** | **5.5** | **7.0** | **4.6** | **5.5** | **0.07** | **0.06** | **6** | **7** | **5** | **6** |
| **Nutrient management (N)** | | | | | | | | | | |
| $T_1$: NPK (Control) | 78.5 | 74.4 | 84.2 | 82.4 | 3.12 | 2.90 | 325 | 320 | 309 | 305 |
| $T_2$: NPK+Mn (f) | 83.1 | 80.4 | 116.4 | 115.2 | 3.28 | 3.24 | 345 | 340 | 328 | 325 |
| $T_3$: NPK+Cu (f) | 80.1 | 75.6 | 103.1 | 100.6 | 3.25 | 3.21 | 337 | 332 | 320 | 315 |
| $T_4$: NPK+Mn (f)+Cu (f) | 88.5 | 84.4 | 126.8 | 125.3 | 3.85 | 3.82 | 385 | 380 | 366 | 362 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 86.2 | 83.5 | 117.3 | 120.3 | 3.58 | 3.54 | 375 | 371 | 356 | 352 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 81.6 | 81.5 | 105.2 | 103.4 | 3.40 | 3.36 | 367 | 362 | 350 | 345 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 89.6 | 86.6 | 133.1 | 130.6 | 4.35 | 4.27 | 394 | 390 | 375 | 371 |
| **LSD (p=0.05) : N** | **2.0** | **1.6** | **4.3** | **5.2** | **0.08** | **0.07** | **7** | **9** | **8** | **10** |
| **V × N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 2. Yield attributes as influenced by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Effective tillers/m$^2$** | | **Ear length (cm)** | | **Grains/ear** | | **1000 grain weight (g)** | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 315 | 310 | 9.1 | 8.8 | 37.7 | 36.3 | 40.5 | 38.7 |
| $V_2$: PBW 621 | 319 | 312 | 9.9 | 9.3 | 42.9 | 41.2 | 40.6 | 39.6 |
| $V_3$: PBW 550 | 300 | 295 | 10.4 | 10.5 | 46.7 | 44.6 | 43.5 | 42.6 |
| **LSD (p=0.05)** | **4** | **5** | **0.6** | **0.7** | **0.6** | **0.8** | **2.6** | **1.5** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 284 | 275 | 8.7 | 8.4 | 41.0 | 39.3 | 37.8 | 35.6 |
| $T_2$: NPK+Mn (f) | 315 | 312 | 9.1 | 9.7 | 41.9 | 40.4 | 41.4 | 39.7 |
| $T_3$: NPK+Cu (f) | 308 | 305 | 9.2 | 9.1 | 41.2 | 39.9 | 39.3 | 37.5 |
| $T_4$: NPK+Mn (f)+Cu (f) | 355 | 349 | 10.4 | 10.3 | 43.7 | 42.0 | 43.9 | 43.7 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 345 | 340 | 10.1 | 9.8 | 42.9 | 41.5 | 42.8 | 41.1 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 337 | 335 | 9.6 | 9.3 | 41.8 | 39.9 | 40.5 | 39.6 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 364 | 355 | 10.7 | 10.4 | 44.6 | 42.3 | 45.0 | 44.7 |
| **LSD (p=0.05) : N** | **6** | **8** | **0.4** | **0.5** | **0.6** | **0.7** | **1.0** | **1.3** |
| **V × N** | **NS** | **NS** | **NS** | **NS** | **1.0** | **1.0** | **NS** | **NS** |

| Table 3. Yield and harvest index as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Grain yield (q/ha)** | | **Straw yield (q/ha)** | | **Biological yield (q/ha)** | | **Harvest Index** | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 46.01 | 44.90 | 63.06 | 69.83 | 109.50 | 114.73 | 42.02 | 39.14 |
| $V_2$: PBW 621 | 44.69 | 45.33 | 67.36 | 72.03 | 112.50 | 117.35 | 39.72 | 38.63 |
| $V_3$: PBW 550 | 46.45 | 47.09 | 61.03 | 63.28 | 107.91 | 109.91 | 43.05 | 42.84 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **0.38** | **0.45** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 29.25 | 32.51 | 45.22 | 52.79 | 74.47 | 85.30 | 39.28 | 38.11 |
| $T_2$: NPK+Mn (f) | 47.57 | 44.93 | 66.79 | 69.22 | 114.36 | 114.15 | 41.60 | 39.36 |
| $T_3$: NPK+Cu (f) | 42.53 | 43.54 | 58.56 | 67.17 | 101.09 | 109.57 | 42.07 | 39.74 |
| $T_4$: NPK+Mn (f)+Cu (f) | 52.65 | 51.73 | 72.13 | 76.45 | 124.78 | 128.17 | 42.19 | 40.36 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 48.70 | 47.43 | 66.54 | 70.16 | 115.24 | 119.00 | 42.25 | 39.85 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 45.14 | 45.20 | 60.89 | 67.04 | 109.03 | 112.27 | 41.40 | 40.26 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 54.15 | 53.71 | 76.59 | 75.81 | 130.74 | 129.52 | 41.42 | 41.46 |
| **LSD (p=0.05) : N** | **4.33** | **4.31** | **7.00** | **4.69** | **11.90** | **8.60** | **0.85** | **0.62** |
| **V × N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 4. Interaction effect of wheat varieties and nutrient management on grain yield (q/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **HD 2967** | | **PBW 621** | | **PBW 550** | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| $T_1$: NPK (Control) | 30.25 | 29.43 | 28.95 | 32.03 | 28.56 | 36.07 |
| $T_2$: NPK+ Mn (f) | 51.22 | 45.16 | 43.15 | 43.10 | 48.35 | 46.52 |
| $T_3$: NPK+Cu (f) | 39.89 | 41.54 | 43.50 | 42.97 | 44.19 | 42.71 |
| $T_4$: NPK+Mn (f)+Cu (f) | 52.13 | 50.95 | 49.53 | 51.86 | 56.30 | 52.38 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 50.82 | 49.30 | 46.53 | 49.48 | 48.74 | 47.66 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 43.01 | 44.92 | 44.32 | 44.53 | 48.09 | 46.22 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 54.73 | 52.99 | 56.82 | 53.29 | 50.90 | 54.85 |
| **LSD (p=0.05)** | | | | | | |

**(2011-12) V × N = NS, (2012-13) V × N = NS**

| Table 5. Interaction effect of varieties and nutrient management on number of grains/ear | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 35.9 | 41.1 | 45.3 | 34.7 | 40.0 | 43.1 |
| $T_2$: NPK+Mn (f) | 37.1 | 41.4 | 46.6 | 36.7 | 40.1 | 44.4 |
| $T_3$: NPK+Cu (f) | 36.3 | 42.1 | 45.4 | 35.5 | 40.9 | 43.2 |
| $T_4$: NPK+Mn (f)+Cu (f) | 39.1 | 44.2 | 48.0 | 38.0 | 42.4 | 45.6 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 38.4 | 43.2 | 47.1 | 37.3 | 41.3 | 45.8 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 36.1 | 42.1 | 47.5 | 35.1 | 41.2 | 43.3 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 39.4 | 44.1 | 49.5 | 37.1 | 42.7 | 47.2 |
| **LSD (p=0.05)** | **V × N = 1.0** | | | **V × N = 1.2** | | |

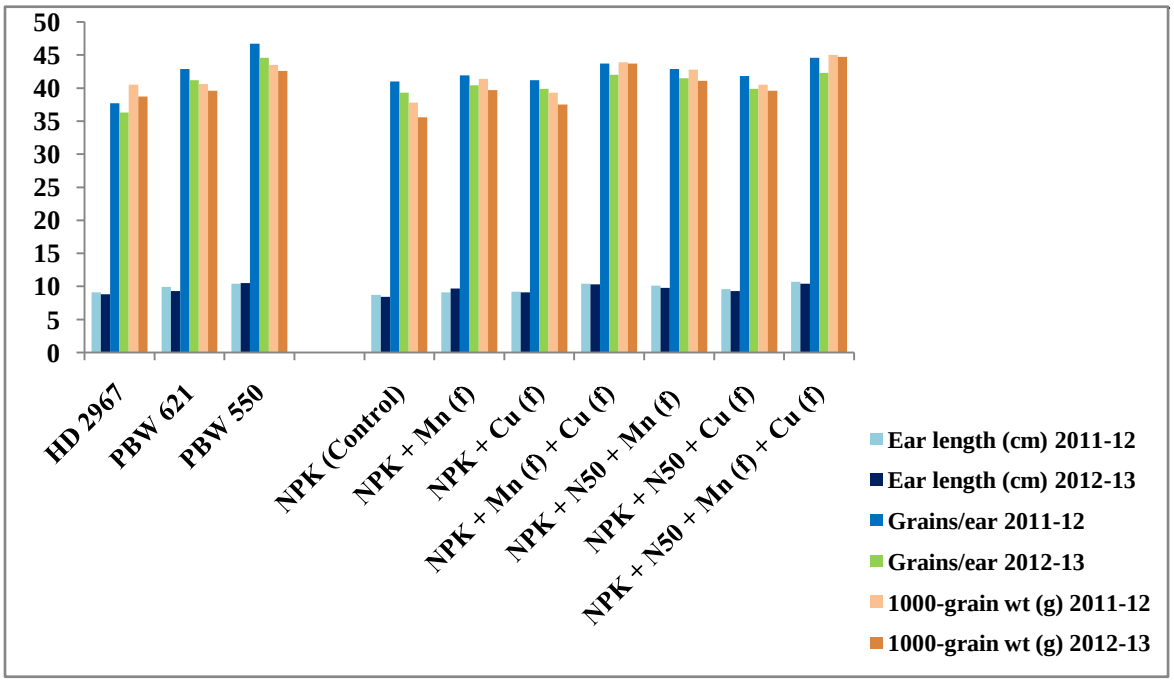



**Fig 2. Ear length, grains/ear and TGW as influenced by varieties and nutrient management**

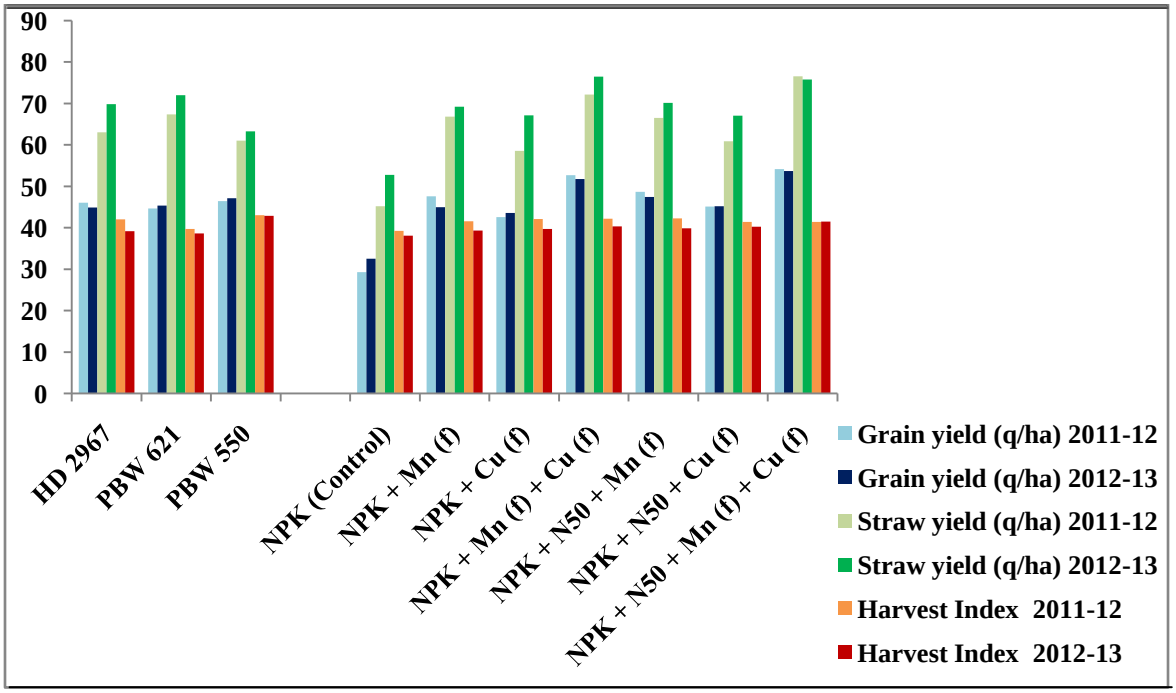



**Fig 3. Effect of varieties and nutrient management on grain yield, straw yield and harvest index**

## Conclusions

Among varieties, PBW 550 recorded the highest values of growth and yield components, straw and grain yield which were significantly better than varieties PBW 621 and HD 2967 during both years of study. Among the treatments of nutrient management, the best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f), which had maximum increasing effects on plant growth leading to increased height, LAI, crop biomass, tiller count, number of fertile tillers/$m^2$, spike length, number of grains/spike, thousand grain weight culminating in enhanced straw, grain yield and improved harvest index.

The apparent mechanism for achieving these enhancements was increase in LAI which increased the photo-synthetic sites and activity resulting in an improved carbohydrate resource base. The fact was substantiated by others also that foliar applied Mn significantly increased tillering, ear-length, number of grains/ear, thousand grain weight, grain yield and crop biomass (20). The findings related to the combined effect of Cu and Mn for significant increase in dry matter, straw and grain yield of wheat were also confirmed (3, 4).

It can be concluded from above research findings that application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and additional dose as top-dressing @ 50 kg/ha 80 DAS in combination with foliar applications of Mn (0.5 %) and Cu (0.1 %) separately in the late reproductive phases (mid-boot, pre-milk and dough) enhanced growth and productivity of the wheat.

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### 3.2 PAPER II

**Grain quality of bread wheat as affected by varieties and nutrient application of nitrogen, manganese and copper**

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**A field experiment was conducted for two years during *rabi* 2011-12 and 2012-13 at Punjab Agricultural University, Ludhiana under timely-sown, irrigated conditions on loamy sand soil (*Typic Ustochrept*) testing near normal in pH, low EC, low in available N, medium in available P and K, low in available Cu and low in available Mn. The experiment was laid out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient treatments ($T_1$: NPK alone as control, $T_2$: NPK + Mn (f), $T_3$: NPK + Cu (f), $T_4$: NPK + Mn (f) + Cu (f), $T_5$: NPK + $N_{50}$ + Mn (f), $T_6$: NPK + $N_{50}$ + Cu (f) and $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) in the sub plots. Three sprays of both 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4$. $5H_2O$ were done separately at three grain development phases such as mid-boot, pre-milk and dough stage. Significant qualitative improvement in physical grain characteristics such as grain appearance score, hectolitre weight and grain hardness and chemical grain characteristic such as SDS-Sedimentation value was observed in variety PBW 550 in comparison to PBW 621 and HD 2967 during both years of study. PBW 621 was found to be significantly higher than HD 2967 in grain hardness. The grain appearance score and hectolitre weight of variety PBW 550 were significantly better than varieties PBW 621 and HD 2967. The variety HD 2967 was significantly higher in β-carotene concentration than PBW 621 and PBW 550 which were statistically at par with each other. Protein content and Phenol reaction score in all the three varieties were statistically non-significant during both the years of study. Significant qualitative improvement in all of these physico-chemical grain characteristics was observed with application of $T_7$: NPK + N50 + Mn (f) + Cu (f) in comparison to all the treatments during both the years. The highest values of grain appearance score (5.8, 6.0); hectolitre weight (77.9, 77.8 kg/hl); grain hardness (11.8, 12.1 kg); SDS-Sedimentation value (53, 55 cc) and β-Carotene (5.68, 5.98 ppm) were observed under the best treatment for both years of study. PBW 550 produced the highest SDS-SV (53, 55 cc) followed by PBW 621 (48, 50 cc) and HD 2967 (45, 47 cc) whereas β-Carotene was highest in HD 2967 (5.37, 5.69 ppm) followed by PBW 550 (4.82, 5.17 ppm) followed by HD 2967 (4.80, 4.93 ppm). All treatments**

**of nutrient management were significantly higher than control in protein content and grain hardness during both seasons. Phenol Reaction Score was found non-significant in all three varieties and nutrient management treatments in both years. The interaction effects of SDS-Sedimentation value and grain appearance score were significant during both seasons. The improvement in grain quality may be attributed to the increased availability of N, Mn and Cu in increasing accumulation of assimilates in the grain during grain filling stage (2, 4, 9).**

Wheat is one of the staple food crops of the world next to rice. The demand for cereals in Asian countries during 2000-2030 was projected to grow at the rate of 1.6 percent compared to the food grains' growth rate of 1.3 percent during the corresponding period (5). Agronomic parameters are significant from production point of view. Food security concerns in India will be taken care of with the passage of food security bill 2013, which targets to provide food grains at subsidized rates to 2/3$^{rd}$ rural population and half of the urban poor population living below the poverty line. According to a recent WHO report, 85 % women and young children below the age of 5 years in India are malnourished and anaemic. Hence, nutritional security is of paramount importance along with food security. Wheat grains must possess desirable quality traits to fulfill the dietary needs of common masses and to tackle the problem of global malnutrition affecting 50 % population of the developing world.

The improvement in wheat quality is a continuous process employing various techniques such as development of new varieties with application of plant breeding and biotechnology. The demand for various industrial end products such as bread, biscuits, cake, pasta is also increasing day by day in the modern world. Alternatively, agronomic methods such as fertilizing crops through soil/foliar methods at critical growth stages can be used for enhancing uptake and assimilation of minerals in wheat grains for qualitative improvement in bread wheat as a short-term, rapid and complementary strategy.

**Materials and methods**

A field experiment was conducted for two years during *rabi* 2011-12 and 2012-13 at Punjab Agricultural University, Ludhiana on loamy sand soil testing near normal pH (7.30), EC (0.15 dS/m), organic carbon (0.24 %), low in available N (180.2 kg/ha), medium in available P (12.5 kg/ha) and meadium in K (142.6 kg/ha), available Cu (0.18 mg/kg soil) lower than the critical level 0.20 mg/kg and available Mn in soil was 3.40 mg/kg lower than the critical level 3.50 mg/kg. The experiment was laid out in split-plot design with treatments comprising of three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient treatments [$T_1$: NPK alone as control, $T_2$: NPK + Mn (f), $T_3$: NPK + Cu (f), $T_4$: NPK + Mn (f) + Cu (f), $T_5$: NPK + $N_{50}$ + Mn (f), $T_6$: NPK + $N_{50}$ + Cu (f), $T_7$: NPK + $N_{50}$ + Mn

(f) + Cu (f)] in the sub plots. Three sprays each of 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4$. $5H_2O$ were done separately at three growth stages such as mid-boot, pre-milk and dough stage. Three varieties were sown on dated November 6-7, 2011 and 2012. Nitrogen as urea was applied @ 125 kg/ha in 3 splits ((1/2 at sowing, 1/4 after first irrigation and 1/4 after second irrigation). Additional dose of nitrogen @ 50 kg/ha was applied 80 days after sowing (DAS). Phosphorous @ 62.5 kg/ha as DAP and potassium @ 30 kg/ha as MOP was applied as full basal dose before sowing. The pH of $CuSO_4.H_2O$ spray solution was neutralized by adding a solution of quicklime (50 % of its total weight) after weighing, soaking overnight and by mixing the supernatant after decantation to make a spray solution of 200 litres per hectare. Spray was done using a knapsack spray pump fitted with a flood-jet nozzle, the spray volume was enough to drench the crop. All foliar sprays contained 0.01 % (v/v) Tween as a surfactant to enhance the penetration of foliar fertilization.

**Soil analysis**

Composit soil samples were taken before sowing and sub sample extracted from it was analyzed to know its physico-chemical properties. Soil texture was determined with standard international pipette method (14). The soil pH was determined by pH meter of Jackson (7). EC was determined by Jackson's salt bridge method (6). Organic carbon was determined by rapid titration method (22). Available nitrogen (21), available phosphorous (12) and available potassium (3) in the soil samples were determined by the standardized procedures. Available manganese and copper concentration of soil samples was determined by DTPA method (9) from 1:2 soil-extractant ratio using DTPA-TEA buffer (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA, pH 7.3).

**Grain quality studies**

Laboratory analysis of the wheat samples drawn in the month of April (after harvesting) for quality tests was done in the wheat quality lab of Plant Breeding Department. The **grain appearance score** was based on the size, shape, color and luster of the grain. It was evaluated subjectively out of a maximum score of 10. The **grain hardness** was measured by using the grain hardness tester supplied by M/S Ogawa Seiki Co. Ltd., Japan by crushing randomly taken ten grains one by one, taking into account the weight, diameter and moisture of the grain. The mean force (kg) required to crush the grain was recorded. **Hectolitre weight** was measured using the apparatus developed by the Directorate of Wheat Research, Karnal, which employs a standard container of 100 ml capacity (11). The grains were weighed and the **hectolitre weight** expressed in kg/hl. The **grain protein content** was estimated using the whole grain analyzer Infratec 1241 supplied by M/S Foss Analytical AB, Sweden. The instrument uses the near infrared light transmitted through the grains. The results are displayed as % protein content as per calibration.

The sodium dodecyl sulphate **sedimentation value** of whole meal samples was estimated according to the method of Axford *et al* (1). A sample weight of 6 g and a rest period of 20 mintues were employed. The **phenol reaction score** was evaluated by treating about 100 grains soaking overnight, with 1 % Phenol solution. The grains were evaluated for extent of darkness out of a score of 10, half an hour after draining off the Phenol solution. **β-carotene content** was determined using water saturated butanol was used to extract the β-Carotene pigment. Absorbance of the filtrate was measured at 440 nm using UV-VIS spectrophotometer using water saturated butanol as blank. The β-Carotene content was calculated as follows:

β-Carotene (ppm) = 0.0105+23.5366 x Optical Density (O.D.)

**RESULTS AND DISCUSSION**

**Influences of varieties and nutrient management of N, Mn and Cu on grain quality**

**Table 1. Physical grain characteristics as affected by wheat varieties and nutrient management**

| Treatment | Grain Appearance Score (Max 10) | | Hectolitre Weight (kg/hl) | | Grain Hardness (kg) | |
|---|---|---|---|---|---|---|
| | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 |
| **Varieties (V)** | | | | | | |
| $V_1$: HD 2967 | 5.1 | 5.4 | 75.1 | 74.9 | 9.2 | 9.7 |
| $V_2$: PBW 621 | 5.3 | 5.5 | 75.7 | 75.4 | 10.8 | 11.0 |
| $V_3$: PBW 550 | 5.7 | 5.8 | 79.5 | 79.4 | 11.9 | 12.1 |
| **LSD (p=0.05)** | **0.2** | **0.2** | **1.2** | **1.7** | **1.0** | **0.9** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK | 5.0 | 5.1 | 75.2 | 75.2 | 9.1 | 9.6 |
| $T_2$: NPK+Mn(f) | 5.2 | 5.4 | 77.2 | 76.8 | 10.4 | 10.8 |
| $T_3$: NPK+Cu(f) | 5.2 | 5.3 | 76.7 | 75.5 | 10.2 | 10.4 |
| $T_4$: NPK+Mn (f)+Cu (f) | 5.4 | 5.5 | 77.7 | 77.4 | 11.1 | 11.5 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 5.5 | 5.7 | 76.9 | 76.9 | 10.8 | 11.2 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 5.4 | 5.6 | 76.7 | 76.0 | 10.7 | 10.8 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 5.8 | 6.0 | 77.9 | 77.8 | 11.8 | 12.1 |
| **LSD (p=0.05) : N** | **0.1** | **0.2** | **1.1** | **1.5** | **0.5** | **0.4** |
| **V x N** | **0.2** | **0.1** | **NS** | **NS** | **NS** | **NS** |

**1. Grain appearance score**

The grain appearance score reflects the status of grains during the ripening period. The well filled grains with sheen and free from stress during the grain filling period score high. The grain appearance score depends upon grain-size, shape, luster and colour. Grains are uniform in shape, bold in size, glossy in luster and amber in color due to higher protein and β-carotene content of grains. Hardness and vitreousness are mechanical and optical properties respectively. Vitreous endosperms have high gliadin content which causes higher adehesion of the protein matrix on starch granules during kernel dessication causing compact endosperm shape (15). The grains with higher grain appearance score are preferred in processing due to higher endosperm to bran ratio.

The variety PBW 550 scored the highest grain appearance score (5.7, 5.8) during both the years and were significantly higher than PBW 621 (5.3, 5.5). PBW 621 was statistically at par with HD 2967 (5.1, 5.4). For the nutrient management treatments, the highest values of grain appearance score were reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f) + Cu (f) (5.8, 6.0), which was significantly higher than $T_5$: NPK+$N_{50}$+Mn (f) (5.5, 5.7) and $T_6$: NPK+$N_{50}$+Cu (f) (5.4, 5.6). The treatment $T_6$ was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (5.4, 5.5). All the treatments $T_2$: NPK+Mn(f) (5.2, 5.4), $T_4$: NPK+Mn+Cu (f) (5.4, 5.5) (f) , $T_5$: NPK+$N_{50}$+Mn(f) (5.5, 5.7) and $T_6$: NPK+$N_{50}$+Cu (f) (5.4, 5.6) were significantly higher than control (5.0, 5.1) except $T_3$: NPK+Cu (f) (5.2, 5.3).

The increased protein content at increase levels of nitrogen as additional dose of N@ 50 kg/ha at 80 DAS before anthesis might have caused the development of more prominent network around the starch granules resulting in more glossy appearance contributing to both grain hardness and protein content. Significant increase in grain appearance score was observed at elevated level of nitrogen applied to the wheat crop just before reproductive phase (15).

The interaction effects were significant in both the years and are given in Table no 3. The interaction values indicated that the highest grain appearance score was reported under the combination of treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) and variety PBW 550 (6.0, 6.2), which was significantly higher than the combination of treatment $T_7$ and variety PBW 621 (5.7, 6.1) which was statistically higher than the combination of treatment $T_7$ and variety HD 2967 (5.4, 5.8). The highest grain appearance score for the combination of control treatment and variety PBW 550 (5.3, 5.3), which was significantly superior to combination of control and variety PBW 621 (5.0, 5.1). The combination of control treatment and variety PBW 621 (5.0, 5.1) were significantly superior to control plots under variety HD 2967 (4.7, 4.9) for grain appearance score.

**2. Hectolitre weight**

Hectolitre weight is the measurement of weight /volume and based on the density, plumpness, size and uniformity of the grains. The results of hectolitre weight are given in Table 1. The hectolitre weight values reflect the conditions during the grain filling period of the crop. Any stress during the grain filling period affects the hectolitre weight negatively. The higher hectolitre weight has lots of plumper grains with higher grain density. The hectolitre weight is positively and linearly co-related to the flour recovery as higher hectolitre weight is indicative of an improved endosperm to bran ratio (17).

The hectolitre weight was comparatively higher during the year 2011-12 than 2012-13 reflecting the better growing conditions during the grain ripening period. The variety PBW 550 recorded the highest hectolitre weight (79.5, 79.4 kg/hl) which was significantly higher than PBW 621 (75.7, 75.4 kg/hl), that was statistically at par with HD 2967 (75.1, 74.9 kg/hl). Under the nutrient treatments the highest values of hectolitre weight (77.9, 77.8 kg/hl) was reported under the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) which was statistically at par with the treatment $T_4$: NPK + Cu (f) + Mn (f) having values (77.7, 77.4 kg/hl) and $T_5$: NPK + $N_{50}$ + Mn (f) (76.9, 76.9 kg/hl) and $T_2$: NPK + Mn (f) reporting values (77.2, 76.8 kg/hl). All of these treatments proved significantly higher than control. Hectolitre weight increased with the elevated nitrogen level due to increase in grain density. Similar results were reported earlier (8).

**3. Grain hardness**

Grain hardness is genetically related to protein content but in Indian wheat, it is more of physical nature indicating the protein denaturation due to the harsh ambient temperature during the grain ripening period. Grain hardness is also related to semolina recovery, which is an endosperm product.The grain hardness is determined by the bonding of starch and protein molecules which is higher at higher level of protein content. The harder grains produce higher chapatties due to a higher production of damaged starch during the grinding of whole wheat which in turn raises the water absorption of dough. The contribution of grain hardness alone to the chapatti quality is about 40 % (10). Grain hardness values are given in Table 1.

The grain hardness values were comparatively higher during the year 2012-13 than 2011-12 reflecting the harsh growing conditions during the grain ripening period. PBW 550 recorded the highest grain hardness (11.9, 12.1 kg) which were significantly higher than PBW 621 (10.8, 11.0 kg). The grain hardness values for variety PBW 621 was significantly higher than HD 2967 (9.2, 9.7 kg) during both the years. Under the treatments of nutrient management, the highest values of grain hardness (11.8, 12.1 kg) were recorded for the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) which was significantly higher than the treatment

$T_5$: NPK + $N_{50}$ + Mn (f) (11.1, 11.5 kg). The treatment $T_5$ was statistically at par with the treatment $T_6$: NPK + $N_{50}$ + Cu (f) (10.7, 10.8 kg) and in turn $T_6$ was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (10.7, 10.8 kg). All the nutrient management treatments were significantly higher than control. It was reported earlier also that the grain hardness increased with increase in nitrogen level (8).

**4. Protein content**

Protein content in wheat is influenced by nitrogen and micronutrient availability at the grain formation stage and other environmental conditions. Protein content is the main feature of grain quality which imparts vitreousness in grains and determines their end use quality. A good chapatti can be baked from a hard grain variety with 9-12 % protein content and high in water absorption with reasonably elastic gluten. The higher water absorption contributes to soft texture of fresh as well as stored chapattis (19). On the other hand for producing good loaf of bread, a grain protein content of 13 % or more is required along with elastic gluten (18).

The perusal of the data in Table 2. indicates that among the three varieties, the protein content values were non-significant in all the three varieties for both the years, however, the numerically highest values of two years for protein content were reported in variety PBW 550 (12.33, 12.62 %) followed by PBW 621 (12.24, 12.31 %) followed by HD 2967 (12.05, 12.15 %). Among the treatments of nutrient management, the highest values of Protein content (13.17, 13.21 %) were reported under the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The treatment $T_7$ was significantly higher than the treatment $T_5$: NPK + $N_{50}$ + Mn (f) (12.57, 12.74 %). The treatment $T_5$ was statistically at par with both the treatments $T_6$: NPK + $N_{50}$ + Cu (f) (12.52, 12.65 %) and $T_4$: NPK + Mn (f) + Cu (f) (12.19, 12.31 %). All the treatments of nutrient management viz. $T_2$: NPK+Mn (f) (11.95, 12.19 %) and $T_4$: NPK+Mn (f) +Cu (f) (12.19, 12.31 %), $T_5$: NPK + $N_{50}$ + Mn (f) (12.57, 12.74 %), $T_6$: NPK + $N_{50}$ + Cu (f) (12.52, 12.65 %) and $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (13.21, 13.17 %) were significantly higher than control (11.33, 11.50 %) during both the years except $T_3$: NPK + Cu (f) (11.69, 11.97 %) which was statistically at par with control.

The significant effect of foliar application of Mn/Cu alone and combined application of N with foliar application of Mn and Cu is crystal clear in comparison to treatment $T_2$: NPK+Mn (f) with NPK control. Protein content significantly increased from control value of (11.33, 11.50 %) to (11.95, 12.19 %) for $T_2$: NPK + Mn (f). Protein content significantly increased from (11.33, 11.50 %) in control to (13.21, 13.17 %) for $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f).

All the nutrient management treatments were significantly higher than control during both the years except NPK + Cu (f) which was statistically at par with control. The foliar application of Mn and Cu along with increased dose of nitrogen improved the protein content significantly.

These results are in accordance with earlier results that reported that delayed N application at the late stage $Z_{31}$ (Zadoks 31$^{st}$ growth stage) of wheat resulted in higher N recoveries which translated into higher protein concentrations in the grain (4, 13, 17). In the treatments of nutrient management, foliar application of micronutrients significantly increased protein contents in wheat grains as compared to control (22), which contributed to increase in grain hardness and sedimentation values also (Fig 1.). Manganese and copper also played an important role in plant processes, including the metabolism of nitrogen. Improved nitrogen metabolism increased the amount of nitrogen that was incorporated into the developing proteins in grains.

**5. SDS-Sedimentation value**

SDS-Sedimentation value is a measure of functional quality of wheat proteins differed significantly among the varieties during both years (Table 2). The sedimentation values were higher for the year 2012-13 due to favourable environmental conditions leading to higher filling of grains and lesser damage to the functional quality of proteins. Generally, the wheat varieties with a sedimentation values of 35-50 cc are preferred for chapatti making whereas one with higher values are used for bread-making.

Among varieties, the highest values of both years for sedimentation values were reported in variety PBW 550 (53, 55 cc), which was significantly superior to PBW 621 (48, 50 cc). PBW 621 and HD 2967 were at par with each other.

During both years, under nutrient management treatments, the highest values of sedimentation values (53, 55 cc) were reported under the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) which was significantly higher than $T_5$: NPK + $N_{50}$ + Mn (f) (51, 53 cc) which was significantly higher than $T_6$: NPK + $N_{50}$ + Cu (f) (49, 52 cc) which was statistically at par with the treatment $T_4$: NPK + Mn (f) + Cu (f) (48, 51 cc).

The interaction effects were significant in both the years which are reflected in Table 4. The interaction values of sedimentation value indicated that the highest values were reported for the combination of treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) and variety PBW 550 (58, 60 cc), which was significantly superior to the combination of treatment $T_7$ and HD 2967 (50, 51 cc) and $T_7$ and PBW 621 (51, 53 cc). The combinations of $T_7$ and varieties HD 2967 and PBW 621 were statistically at par with each other. The lowest values of sedimentation value were reported in the

combination of treatment control and variety HD 2967 (39, 41 cc) which was statistically inferior to combination of treatment control and variety PBW 621 (45, 47 cc), which was statistically inferior to combination of treatment control and variety PBW 550 (49, 51 cc).

In the year 2012-13, all nutrient treatments were significantly higher than control. These results are in line of protein content. Actually, gluten up to 90 % is constituted by the proteins and the improvement in proteins caused the higher development of significantly higher gluten and consequently in the improvement in sedimentation value (Fig 2.). Similar trend was reported earlier (10).

**6. β-Carotene :**

β-carotene is a pigment in wheat grain and imparts a characteristic golden hue to wheat semolina. β -carotene is a precursor of vitamin A and it is of nutritional significance. Cu is also involved in various cell and plant growth functions as a constituent of cytochrome oxidase and component of many enzymes and promotes synthesis of vitamin A. β-carotene concentration recorded in experiment of different treatment combinations is given in the Table 2.

During the year 2011-12 and 2012-13, the highest value of β-carotene was recorded in HD 2967 (5.37, 5.69 ppm) which was significantly higher than PBW 550 (4.82, 5.17 ppm). The variety PBW 550 was at par with PBW 621 (4.80, 4.93 ppm). All treatments of nutrient management were significantly higher than control during both the years. The highest values of β-carotene (5.68, 5.98 ppm) were reported under the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) which was significantly higher than the treatment $T_5$: NPK + $N_{50}$ + Mn (f) (5.44, 5.63 ppm). Further, the treatment $T_5$ was statistically at par with $T_6$: NPK+$N_{50}$+Cu (f) (5.37, 5.59 ppm) and in turn the treatment $T_6$ was at par with $T_4$: NPK + Mn (f) + Cu (f) (5.21, 5.51 ppm).

An improvement in the β-carotene concentration was reported up to a level of 200 kg/ha (15). It is imperative to apply additional dose of nitrogen near reproductive phase for attaining high content of carotene pigments. It is pertinent to mention here that enhanced β-carotene levels in wheat grains will further help in the higher absorption of metal cations like Cu and Mn in human gut by reducing the anti-nutrient like phytic acid (dephytisation) concentration and decreasing the chelation of metal cations in the wheat grains thereby raising its nutritional value. The interaction effects were non-significant in both the years (Table 2).

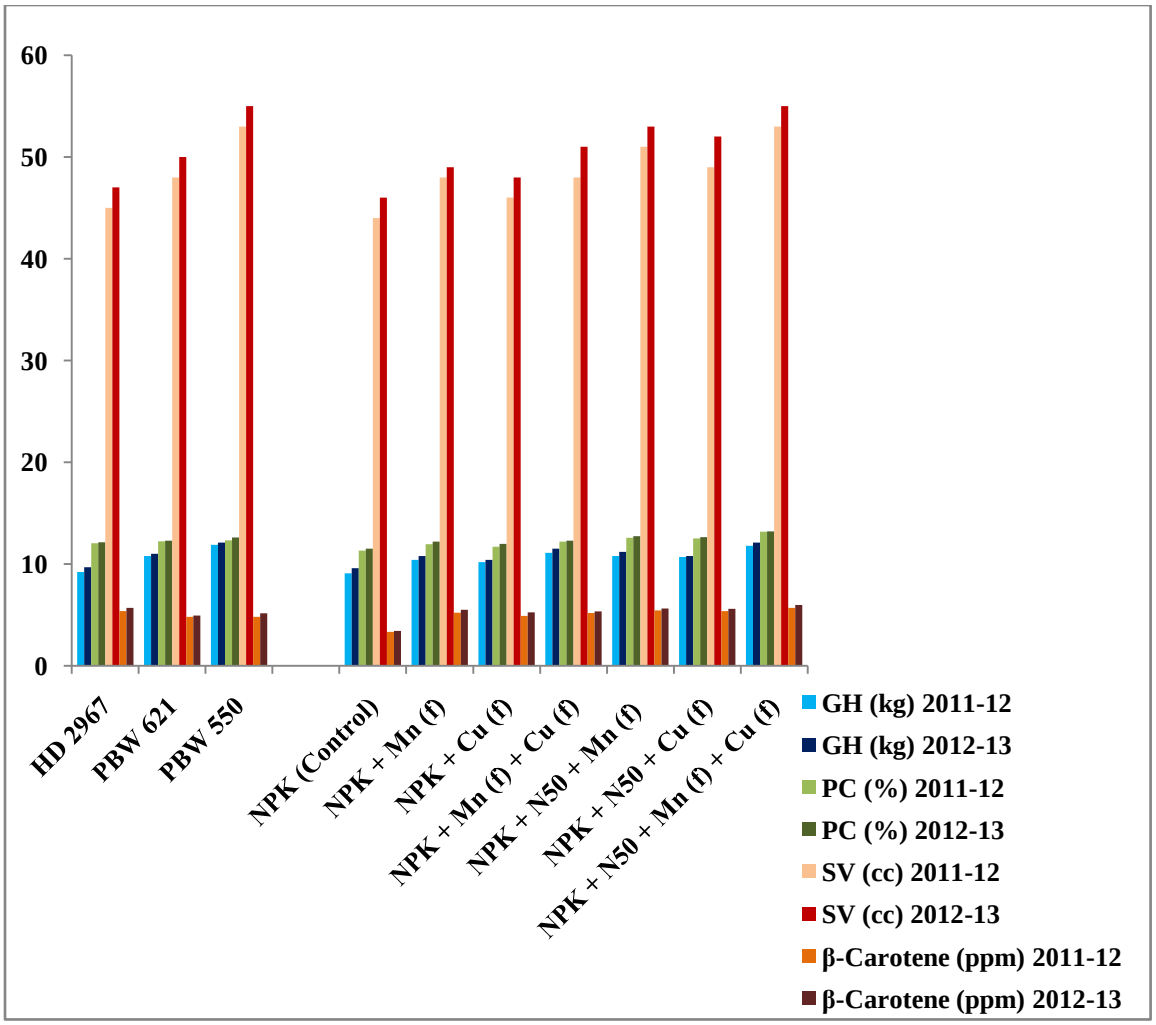



**Fig 1. Grain hardness, protein content, sedimentation value and β-carotene as affected by varieties and nutrient management**

## 7. Phenol Reaction Score

The phenol reaction score is indicative of the Tyrosinase enzyme activity causing darkening of dough during storage and processing was comparatively higher during 2011-12 than 2012-13 (Table 2.), because milder environment might have facilitated the escape of the enzyme. The lower phenol reaction score value is desirable as such dough can be stored for long and the risk of darkening and nutritional losses is minimum. Phenol Reaction Score was found non-significant irrespective of varieties, nutrient treatments and their interaction during both years of study.

**Conclusions**

Among wheat varieties, significant qualitative improvement in grain appearance score, hectolitre weight and grain hardness and SDS-Sedimentation value was observed in variety PBW 550 in comparison to PBW 621 and HD 2967 during both years of study. The variety PBW 621 was found to be significantly higher than HD 2967 in grain hardness. Both varieties PBW 621 and HD 2967 were statistically inferior to PBW 550 but at par with each other for hectolitre weight and grain appearance. The variety HD 2967 was significantly higher in β-carotene content than PBW 621 and PBW 550. The varieties PBW 621 and PBW 550 were statistically at par with each other for β-carotene content. All the three varieties were non-significant in Protein content and Phenol reaction score in both years of study. Significant qualitative improvement in the physico-chemical grain characteristics was observed with application of $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) in comparison to all other treatments during both the years. All treatments of nutrient management were significantly higher than control for protein content and grain hardness during both seasons. The highest values of grain appearance score, hectolitre weight, grain hardness, SDS-Sedimentation value and β-Carotene were observed under this best treatment for both years. The interaction effects of SDS-Sedimentation value and grain appearance score were significant during both seasons.

It can be concluded from above research findings that application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 days after sowing of wheat combined with foliar application of copper and manganese applied separately at mid-boot, pre-milk and dough stages caused significant qualitative improvement in the wheat grains.

| Table 2. Chemical grain characteristics as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Protein content ( %)** | | **SDS-Sedimentation value (cc)** | | **β-Carotene (ppm)** | | **Phenol Reaction Score (Max 10)** | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 12.05 | 12.15 | 45 | 47 | 5.37 | 5.69 | 3.9 | 3.8 |
| $V_2$: PBW 621 | 12.24 | 12.31 | 48 | 50 | 4.80 | 4.93 | 3.7 | 3.6 |
| $V_3$ : PBW 550 | 12.33 | 12.62 | 53 | 55 | 4.82 | 5.17 | 3.6 | 3.4 |
| **LSD (p=0.05)** | **NS** | **NS** | **3** | **4** | **0.12** | **0.35** | **NS** | **NS** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$ : NPK (Control) | 11.33 | 11.50 | 44 | 46 | 3.34 | 3.42 | 4.0 | 3.9 |
| $T_2$ : NPK+Mn (f) | 11.95 | 12.19 | 48 | 49 | 5.21 | 5.51 | 3.8 | 3.6 |
| $T_3$ : NPK+Cu (f) | 11.69 | 11.97 | 46 | 48 | 4.92 | 5.25 | 3.8 | 3.6 |
| $T_4$ : NPK+Mn (f)+Cu (f) | 12.19 | 12.31 | 48 | 51 | 5.20 | 5.36 | 3.5 | 3.4 |
| $T_5$ : NPK+$N_{50}$+Mn (f) | 12.57 | 12.74 | 51 | 53 | 5.44 | 5.63 | 3.6 | 3.5 |
| $T_6$ : NPK+$N_{50}$+Cu (f) | 12.52 | 12.65 | 49 | 52 | 5.37 | 5.59 | 3.8 | 3.7 |
| $T_7$ : NPK+$N_{50}$+Mn (f)+Cu (f) | 13.17 | 13.21 | 53 | 55 | 5.68 | 5.98 | 3.4 | 3.3 |
| **LSD (p=0.05) : N** | **0.44** | **0.52** | **1** | **1** | **0.18** | **0.31** | **NS** | **NS** |
| **V × N** | **NS** | **NS** | **2** | **3** | **NS** | **NS** | **NS** | **NS** |

| Table 3. Interaction effect of varieties and nutrient management on Grain Appearance Score (Max 10) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 4.7 | 5.0 | 5.3 | 4.9 | 5.1 | 5.3 |
| $T_2$: NPK+Mn (f) | 4.9 | 5.2 | 5.6 | 5.3 | 5.3 | 5.7 |
| $T_3$: NPK+Cu (f) | 4.8 | 5.2 | 5.7 | 5.1 | 5.2 | 5.7 |
| $T_4$: NPK+Mn (f)+Cu (f) | 4.9 | 5.4 | 5.8 | 5.3 | 5.4 | 5.8 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 5.0 | 5.6 | 5.9 | 5.5 | 5.6 | 6.0 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 5.0 | 5.3 | 5.8 | 5.5 | 5.5 | 5.9 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 5.4 | 5.7 | 6.0 | 5.8 | 6.1 | 6.2 |
| **LSD (p=0.05)** | **V × N = 0.22** | | | **V × N = 0.1** | | |

| Table 4. Interaction effect of varieties and nutrient management on SDS-Sedimentation Value (cc) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 39 | 45 | 49 | 41 | 47 | 51 |
| $T_2$: NPK+Mn (f) | 45 | 48 | 52 | 47 | 48 | 53 |
| $T_3$: NPK+Cu (f) | 42 | 46 | 49 | 45 | 48 | 51 |
| $T_4$: NPK+Mn (f)+Cu (f) | 45 | 46 | 52 | 48 | 49 | 56 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 49 | 50 | 55 | 51 | 51 | 57 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 45 | 48 | 53 | 49 | 51 | 56 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 50 | 51 | 58 | 51 | 53 | 60 |
| **LSD (p=0.05)** | **V × N = 2** | | | **V × N = 3** | | |

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## 3.3 PAPER III

**Agronomic biofortification, nutrient uptake and productivity of wheat (*Triticum Aestivum* L.) as influenced by fertilization strategies.**

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**The investigation was conducted for two cropping seasons 2011-12 and 2012-13 at research farm of Department of Agronomy, Punjab Agricultural University, Ludhiana in timely-sown, irrigated conditions in a loamy sand soil (*Typic Ustochrept*) testing near normal in pH, low EC, low in available N, medium in available P and K, low in available Cu and available Mn. The experiment was laid out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient treatments [$T_1$: NPK alone recommended dose as control, $T_2$: NPK + Mn (f), $T_3$: NPK + Cu (f), $T_4$: NPK + Mn (f) + Cu (f), $T_5$: NPK + $N_{50}$ + Mn (f), $T_6$: NPK + $N_{50}$ + Cu (f) and $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f)] in the sub plots. Three sprays of 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4$. $5H_2O$ were done separately at three critical grain development stages such as mid-boot, pre-milk and dough stage. The uptake of N, Cu and Mn improved yield and enriched wheat grains with Mn and Cu. Uptake of N, Mn and Cu increased significantly in grain, straw and crop. Nitrogen content in grain was significantly higher in the wheat variety PBW 550 (1.86, 1.89 %) which was significantly higher than PBW 621 (1.77, 1.82 %) which was significantly higher than HD 2967 (1.72, 1.76 %). Nitrogen uptake (kg/ha) in grain was non-significant among varieties in the first year but differed significantly among PBW 550 (88.13 kg/ha) and PBW 621 (82.48 kg/ha) in the second year. The varieties HD 2967 (79.02 kg/ha) and PBW 621 (82.48 kg/ha) were statistically at par with each other in nitrogen uptake. The wheat variety PBW 550 recorded the highest N content ( %), uptake in straw and total uptake in crop followed by PBW 621 followed by HD 2967. The increased dose of nitrogen before heading and foliar application of Mn and Cu at critical grain filling stages significantly increased N content ( %) and uptake in grain, straw and total uptake by crop. The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) in N content and uptake in grain, straw and total uptake by crop. Grain Mn concentration was not affected significantly by varieties but differed significantly among the treatments of nutrient management whereas the highest grain Cu concentration was recorded by PBW 550 (4.72, 4.03 µg/g) which was**

**statistically at par with HD 2967 (4.65, 4.01 µg/g) but both of these varieties proved significantly higher than PBW 621 (4.24, 3.72 µg/g). Grain yield increased by (85.1, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) for best treatment i.e. $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The straw yield of wheat increased by (69.37, 43.61 %) from (45.22, 52.79 q/ha) in control to (76.59, 75.81 q/ha) for best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Grain Mn concentration increased by (46.57, 52.32 %) from (25.62, 25.25 µg/g) control to (37.55, 38.46 µg/g) under treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Grain Cu concentration increased by (74.11, 94.65 %) from (3.40, 2.99 µg/g) in control to (5.92, 5.82 µg/g) under the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Overall, application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 DAS and foliar applications of Cu (0.1 %) and Mn (0.5 %) increased crop growth, dry biomass, straw yield, grain yield and enhanced Cu and Mn concentrations in grain and straw significantly over control.**

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Wheat is the most widely cultivated crop which provides food and nutrition to two-third population of the world. India ranks second in wheat production in the world next to China. Wheat is the second staple food crop of India after rice, India has a total production of 95.91 million tonnes which is 12 % of the world food production from 31.34 million hectares of land with productivity of 30.61 q/ha during *rabi* 2012-13 (2). It was grown on an area of 3.51 million ha in Punjab with production of 16.59 million tonnes and grain yield of 47.2 q/ha during *rabi* 2012-13 (2).

**Cause of soil micronutrient deficiencies:**

A number of wheat varieties have been developed in the past and introduced in the rice-wheat cropping system in the Indo-Gangetic plains (IGP), which has helped in enhancing food grain production substantially thereby reducing starvation and protein malnutrition. An estimated nine million hectares in the IGP is planted under rice-wheat crop rotation (14). Micronutrient analysis of soil and plant samples across IGP revealed that 1 % soils and 22 % plants were deficient in Cu; and 4 % soils and 11 % plants were deficient in Mn (15).

Intensive mining of minerals by exhaustive crops and continuous growing of cereal crops in cropping system has caused greater depletion of micronutrient reserves from the soil causing deficiencies of micronutrients. According to an estimate, wheat crop removes 141-330 g Mn and 34-50 g Cu for every 2 tonnes of wheat grains. As much as 5 and 4 % soils in India are deficient in manganese and copper respectively (20, 26). Whereas in Punjab state 11 and 2 % soils are deficient in Mn and Cu (5).These deficiencies cause hidden hunger, lower yields, crop failures

and poor accumulation of trace elements into edible plant-parts/grains and poor nutrition to human beings.

**Need of nutrient enrichment of wheat grains for humans**

Wheat is inherently very low in the bioavailability of Mn and Cu. The availability range of Cu and Mn in the wheat varieties in India varies from 2-5 and 24-30 mg/kg respectively (2).The recommended dietary allowance (RDA) of micronutrients for young adults in India ranges from 2 to 3 mg/day for Cu and 5-7 mg/day for Mn (1).These nutrients are mostly present in the wheat bran which is usually removed during flour-making and normally white flour (endosperm) is consumed as bread. Normally, an adult person consumes about 250-300 grams of wheat flour as bread. The concentration of micronutrients in most of the wheat varieties needs enhancement in grain to fulfill the daily human requirement.

**Role of manganese in plant and human health**

The normal concentration of Mn in plants typically ranges from 20 to 500 mg/kg. Plant parts having Mn concentration below 15 to 20 mg/kg are considered deficient. Mn is absorbed by plants as $Mn^{2+}$ in molecular combination with certain natural and synthetic complexing agents. Mn is relatively immobile element and deficiency symptoms usually show up first in the younger leaves. Mn is involved in evolution of oxygen in photosynthesis. It also takes part in redox reactions, decarboxylation and hydrolysis reactions. Mn is needed for activity of many enzymatic reactions in the citric acid cycle and influences auxin levels in plants. Mn is required for enzyme activation in electron transport and disease-resistance (19, 22).

Mn is required in human body for bone development, amino acid, lipid and carbohydrate metabolism. Mn is required for various enzymes such as mitochondrial MnSOD (manganese super-oxide dismutase), glutamine synthetase, arginase, activation of several enzymes such as hydrolases, transferases and carboxylases. Mn in transported in the body by transferrin and by microglobulins and albumin. The dietry sources of Mn are whole grain, rice, tea and nuts. Mn is toxic in excess causing a Perkinson like syndrome in brain.

**Role of copper in plant and human health**

Copper (Cu) is absorbed by plants as $Cu^{2+}$ ion as part of either natural or synthetic-organic complexes. Its normal concentration in plant tissue ranges from 5 to 200 mg/kg. Cu is unique in its involvement in enzymes and cannot be replaced by any other metal ion (22). Cu is involved in various cell and plant growth functions as a constituent of cytochrome oxidase and component of many enzymes and promotes synthesis of vitamin A (19).

Amounts of exchangeable metals in soil are related to their concentration in soil solution as soil pH affects exchangeable Mn and Cu similarly. The activity (consequent bioavailability) of

Mn and Cu decreases 100 fold for each unit decrease in soil pH. The phyto-availability of Cu in many agricultural soils is low and Cu supplied to the soil becomes rapidly unavailable to the plants (11)

There is about 80 mg of Cu in the adult human body with maximum concentration in liver and brain. Cu as a cofactor of lysyl oxidase is required in the cross-linking of collagen and elastine. Cu deficiency in human beings causes stunting of bone growth and extreme conditions like osteoporosis.

**Fertilization strategies for mineral-densing of wheat grains with Cu and Mn**

Breeding new plant genotypes (genetic biofortification) for high grain concentration of micro-elements is the long-term strategy to address the global problem of mineral malnutrition. Other approaches like food supplementation and medication are costly and may cause toxicities and nutrient imbalance within human bodies. A rapid and complementary approach such as agronomic biofortification is required for mineral enrichment of food crops. This can be achieved through fertilization of staple food crops like wheat with soil and foliar application of micronutrient fertilizers at critical phenological phases such as boot, milk and dough stages.

**Physiological basis of agronomic biofertification**

**Biofortification** is the process of increasing the natural content of nutrients in edible part of crop plants (28).The supply of minerals to the developing cereal grain originates from two sources: first as a result of direct uptake from the soil and second from the remobilization of stored minerals in leaves as they fall during the stage of grain filling. Concentration or density is the amount of nutrient per unit of grain dry weight, which is a more important measure of micronutrient supply in grain than micronutrient content (the total amount of nutrient per seed or plant).

Plants are capable of absorbing soluble compounds and gases through leaves. Application of foliar spray implies that nutrient applied will be absorbed from the point of application (leaves) to the point of utilization (growing tissue). An export of nutrient from leaves and transport within the stem occurs in phloem, while transport in the stem may occur in either phloem or xylem (24). Soil/foliar application of nitrogenous and specific micronutrient fertilizers at critical growth stages of wheat may contribute towards mineral enrichment of grain and yield-enhancement by improving their availability because Mn is involved in photosynthetic electron transport (19). The process of mineral-enrichment takes place well above the sufficiency level of a nutrient with-in the crop plant.

**Significance of agronomic biofortification:**

The main advantages of agronomic biofortification are immense (Annexure X). It is done on crop cultivars popular among farmers and the produce is acceptable to the consumers.This approach is beneficial to the farmers because they get nutrient-enriched seed which can withstand biotic and abiotic stresses in a better way.The farmer is protected from buying new seeds and investment in micronutrient fertilizers is saved.Gain in the micronutrient concentration is also associated with increase in yield and quality. The application rates of micronutrient fertilizers applied as foliar spray are much smaller. Hence, this technique is a win-win approach for all stakeholders.

**Material and methods:**

Before sowing**,** bulk surface soil samples (0–15 and 15-30 cm depth) were collected from research field of the Department of Agronomy, Punjab Agricultural University, Ludhiana representing the Indo-Gangetic alluvial plains, situated at $30^0$ $56^/$ N latitude and $75^0$ $52^/$ E longitude and at an altitude of 247 meters above mean sea level. The air-dried soil was ground to pass through a 2.0-mm sieve, and a sub-sample of the sieved soil was analyzed for various mechanical and physico-chemical properties. Soil texture was loamy-sand (sand 82.30 %; silt 7.2 %; clay 10.5 %) as determined by International pippet method (23). The soil had pH 7.30 in a saturated soil paste (12). Electrical conductivity of the saturated soil paste extract was low having value 0.15 dS/m (13). Soil organic C was low, determined by Walkley and Black's rapid titration method (23), was 0.24 % in soil. Plant-available Mn and Cu in the soil were low with values 3.40 and 0.18 mg/kg soil, respectively, as extracted by DTPA method (0.005 M DTPA + 0.01 M $CaCl_2$+0.1 M TEA, pH 7.3) (17) and measured on an atomic absorption spectrophotometer (Varian-AAS FS 240 Model). Available nitrogen (27), available phosphorous (21) and available potassium (6) in the soil samples were determined by the standardized procedures

The soil samples were collected layer wise from three different spots viz. 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm depth in experimental field. The samples of the respective depths were composited to determine the physical soil moisture constants. The field capacity and permanent wilting point by pressure plate apparatus (25) of 0-180 cm rhizosphere were 36.56 cm and 11.55 cm respectively. Hence, the available water in the 0-180 cm of soil profile comes out to be 25.01 cm. The average bulk density of the soil was 1.58 $g/cm^3$ (Core Sampler Method (7).

The experiment was laid out in the split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient treatments [$T_1$: NPK alone as control, $T_2$: NPK + Mn (f), $T_3$: NPK + Cu (f), $T_4$: NPK + Mn (f) + Cu (f), $T_5$:

NPK + $N_{50}$ + Mn (f), $T_6$: NPK + $N_{50}$ + Cu (f), $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f)] in the sub plots. Three sprays each of 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4.5H_2O$ were done separately at three critical stages of grain filling such as mid-boot, pre-milk and dough stage. Three varieties were sown on dated November 6-7, 2011 and 2012. Recommended dose of nitrogen in the form of urea was applied @ 125 kg/ha in 3 splits (1/2 at sowing, 1/4 after first irrigation and 1/4 after second irrigation). Additional dose of nitrogen @ 50 kg/ha was applied 80 days after sowing (DAS). Phosphorous @ 62.5 kg/ha as DAP and potassium @ 30 kg/ha as MOP was applied as full basal dose before sowing. The pH of $CuSO_4.5H_2O$ spray solution was neutralized by adding a solution of quicklime (50 % of its total weight) after weighing, soaking overnight and by mixing the supernatant after decantation to make a spray solution of 200 litres per hectare. Spray was done at using a knapsack spray pump fitted with a flood-jet nozzle, the spray volume being enough to drench the crop. All foliar sprays contained 0.01 % (v/v) Tween-20 as a surfactant to enhance the penetration of foliar fertilization through cuticle of leaf surface.

| Table 1. Grain and straw yield as affected by wheat varieties and nutrient management | | | | |
|---|---|---|---|---|
| **Treatment** | **Grain yield (q/ha)** | | **Straw yield (q/ha)** | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| **Varieties (V)** | | | | |
| $V_1$: HD 2967 | 46.01 | 44.90 | 63.06 | 69.83 |
| $V_2$: PBW 621 | 44.69 | 45.33 | 67.36 | 72.03 |
| $V_3$: PBW 550 | 46.45 | 47.09 | 61.03 | 63.28 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **NS** |
| **Nutrient management (N)** | | | | |
| $T_1$: NPK | 29.25 | 32.51 | 45.22 | 52.79 |
| $T_2$: NPK+Mn(f) | 47.57 | 44.93 | 66.79 | 69.22 |
| $T_3$: NPK+Cu(f) | 42.53 | 43.54 | 58.56 | 67.17 |
| $T_4$: NPK+Mn (f)+Cu (f) | 52.65 | 51.73 | 72.13 | 76.45 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 48.70 | 47.43 | 66.54 | 70.16 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 45.14 | 45.20 | 60.89 | 67.04 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 54.15 | 53.71 | 76.59 | 75.81 |
| **LSD (p=0.05) : N** | **4.33** | **4.31** | **7.00** | **4.69** |
| **V x N** | **NS** | **NS** | **NS** | **NS** |

**Table 2. Nutrient concentration as influenced by wheat varieties and nutrient management**

| Treatment | Nutrient concentration (µg/g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Manganese | | | | Copper | | | |
| | Grain | | Straw | | Grain | | Straw | |
| | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 32.34 | 31.87 | 29.99 | 28.24 | 4.65 | 4.01 | 3.80 | 3.06 |
| $V_2$ : PBW 621 | 32.38 | 31.00 | 28.69 | 27.57 | 4.24 | 3.72 | 3.25 | 2.77 |
| $V_3$ : PBW 550 | 31.84 | 30.49 | 27.58 | 26.34 | 4.72 | 4.03 | 3.88 | 3.08 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **NS** | **0.18** | **0.19** | **0.17** | **0.18** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 25.62 | 25.25 | 20.17 | 19.76 | 3.40 | 2.99 | 2.41 | 2.02 |
| $T_2$: NPK+Mn (f) | 32.88 | 31.73 | 28.89 | 27.21 | 3.82 | 3.10 | 2.73 | 2.15 |
| $T_3$: NPK+Cu (f) | 27.92 | 27.67 | 24.44 | 22.58 | 4.31 | 3.55 | 3.32 | 2.60 |
| $T_4$: NPK+Mn (f)+Cu (f) | 36.53 | 36.44 | 35.59 | 33.65 | 5.39 | 4.62 | 4.40 | 3.67 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 34.56 | 31.94 | 28.98 | 27.45 | 4.01 | 3.24 | 3.02 | 2.29 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 31.28 | 27.36 | 25.86 | 23.59 | 4.92 | 4.15 | 3.93 | 3.20 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 37.55 | 38.46 | 37.34 | 37.46 | 5.92 | 5.82 | 5.60 | 4.88 |
| **LSD (p=0.05) N** | **2.54** | **2.41** | **2.79** | **2.74** | **0.42** | **0.26** | **0.34** | **0.28** |
| **V × N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

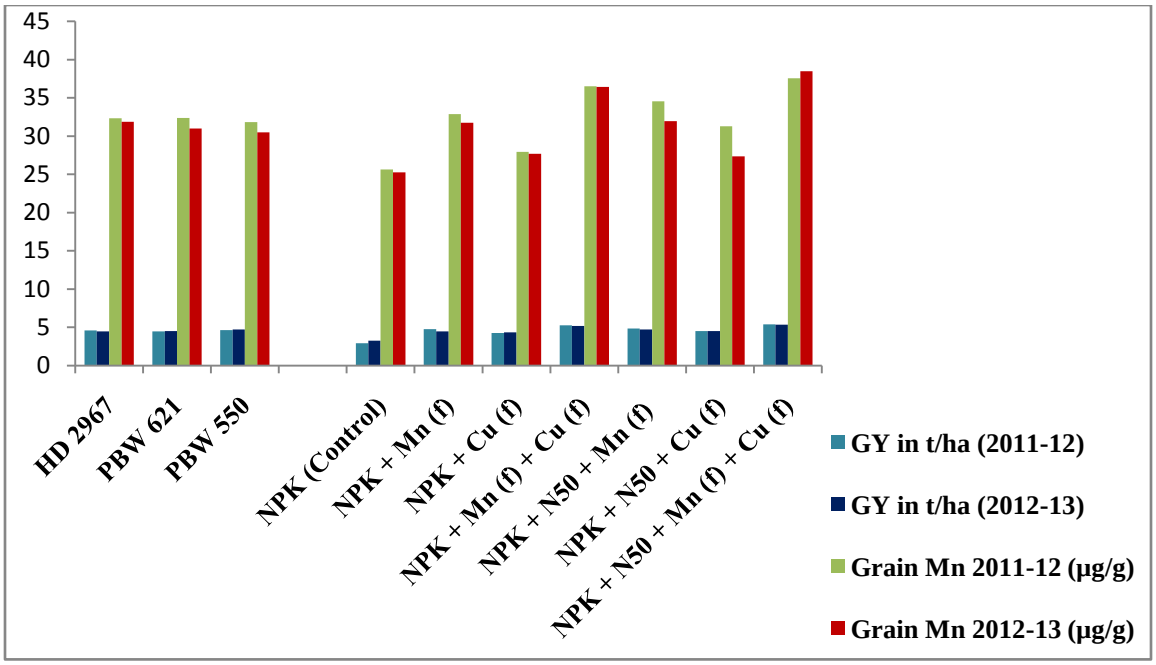



**Fig 1: Effect of varieties and nutrient management on grain yield and grain concentration of Mn**

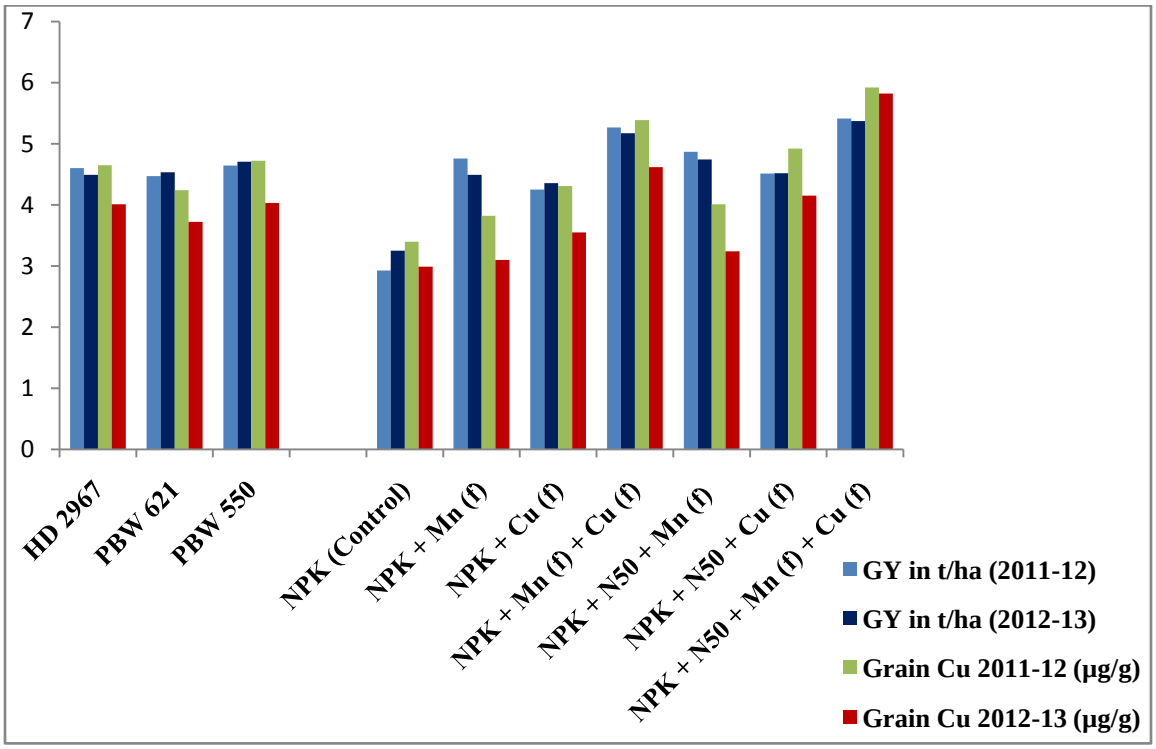



**Fig 2: Effect of varieties and nutrient management on grain yield and grain concentration of Cu**

**Results and Discussion:**

**Grain yield (q/ha)**

Crop productivity is the rate at which a crop accumulates biomass which depends primarily on the rate of photosynthesis. The yield of wheat is composed of yield components such as effective tillers/$m^2$, number of grains/ear, spike length and thousand grain weight (TGW). Though TGW does exert an influence on grain yield but its effect is lower than spike length and number of grains/spike (22). The data on grain yield is presented in Table 1, Fig 1.

All the three varieties were statistically at par with each other for grain yield. Similar results were reported earlier (10). All the treatments of nutrient management were significantly higher than control (29.25, 32.51 q/ha). $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) was the best treatment (54.15, 53.71 q/ha), which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (52.65, 51.73 q/ha). The treatment $T_4$ was statistically at par with the treatment $T_5$: NPK + $N_{50}$ + Mn (f) (48.70, 47.43 q/ha). Further, $T_5$ was significantly higher than other treatments such as $T_2$: NPK+Mn (f) (47.57, 44.93 q/ha), $T_3$: NPK+Cu (f) (42.53, 43.54 q/ha) and $T_6$: NPK+$N_{50}$+Cu (f) (45.14, 45.20 q/ha). The significant effect of foliar application of Mn and Cu is apparently visible with comparison of $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f) with NPK control. Grain yield increased by (62.63, 38.20 %) from (29.25, 32.51 q/ha) in control to (47.57, 44.93 q/ha) for $T_2$: NPK + Mn (f). Grain yield increased by (45.40, 33.93 %) from (29.25, 32.51 q/ha) in control to (42.53, 43.54 q/ha) for $T_3$: NPK + Cu (f). Grain yield has increased by (85.10, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) for best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f).

Mn promoted evolution of oxygen in photosynthesis, enzyme activation in electron transport and disease-resistance (19) thereby enhancing phtosynthates, their increased translocation to grain and finally increased yield in the treatments $T_2$, $T_4$, $T_5$ and $T_7$. Copper involved in various cell and plant growth functions as a constituent of cytochrome oxidase and component of many enzymes and promoted synthesis of vitamin A (19) resulting in increased photosynthesis and photosynthates and their translocation into grain thereby increasing crop yield in the treatments $T_3$, $T_4$, $T_6$ and $T_7$.

The increase in grain yield was due to the cumulative effect of increase in all the yield-attributing components such as such as effective tillers/$m^2$, number of grains/ear, spike length and thousand grain weight (Table 2.). Additional N supply before heading and foliar application of Mn and Cu might have increased grain yield through more allocation of dry matter to grains. Similar results were reported earlier also (4, 7,9, 15, 18).

**Straw yield (q/ha)**

Straw yield also makes important contribution to the overall crop value.The straw yield is presented in Table 1. All the three varieties were statistically at par with each other for straw yield.

All the treatments of nutrient management, were significantly higher than control (45.22, 52.79 q/ha). The treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment (76.59, 75.81 q/ha), which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (72.13, 76.45 q/ha). The treatment $T_4$: NPK+Mn (f)+Cu (f) was significantly superior to $T_3$: NPK+Cu (f) (58.56, 67.17 q/ha) by (23.17, 13.82 %) and $T_6$: NPK+$N_{50}$+Cu (f) (60.89, 67.04 q/ha) by (25.78, 14.04 %). The significant effect of foliar application of Mn and Cu is apparently visible with comparison of $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f) with NPK control. Straw yield increased by (14.05, 3.10 %) from (58.56, 67.17 q/ha) in control to (66.79, 69.22 q/ha) for $T_2$: NPK + Mn (f). Straw yield increased by (29.50, 27.24 %) from (45.22, 52.79 q/ha) in control to (58.56, 67.17 q/ha) for $T_3$: NPK + Cu (f). Straw yield has increased by (68.37, 43.61 %) from (45.22, 52.79 q/ha) in control to (76.59, 75.81 q/ha) for best treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f).

The increase in straw yield was due to the cumulative effect of increase in all the straw yield attributing indices such as plant height, dry matter accumulation, LAI and number of tillers (Table 1.). The increase in straw yield may be due to the combined effect of Cu and Mn increased wheat dry matter, straw yield and grain yield significantly over control. Similar results were given earlier (3).

**Effect on grain manganese concentration**

The perusal of data in Table 3.indicates that all the three wheat varieties were statistically at par with each other in grain Mn concentration during both years of study.

All the treatments of nutrient management (except $T_3$: NPK+Cu (f) (27.97, 27.62 µg/g) were significantly higher than control (25.62, 25.25 µg/g). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (37.55, 38.46 µg/g) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (36.53, 36.44 µg/g). Further, the treatment $T_4$ was statistically at par with $T_5$: NPK+$N_{50}$+Mn (f) (34.56, 34.94 µg/g). Grain Mn concentration increased by (46.57, 52.32 %) from (25.62, 25.25 µg/g) control to (37.55, 38.46 µg/g) under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). The significant effect of foliar application of Mn is apparently visible with comparison of $T_2$: NPK+Mn (f) with NPK control. Grain Mn concentration increased by (28.34, 25.66 %) from (25.62, 25.25 µg/g) in control to (32.88, 31.73 µg/g) for $T_2$: NPK+Mn (f). Grain Mn concentration increased by (34.89, 26.50 %) from (25.62, 25.25 µg/g) in control to (34.56, 31.94 µg/g) for $T_5$: NPK+$N_{50}$+Mn (f). The increase in grain manganese concentration may be due to the

synergistic effect of increased dose of nitrogen and foliar application of Mn. Similar results were reported earlier also (8).

**Effect on straw manganese concentration**

The perusal of data in Table 3 that among wheat varieties, all the three varieties proved statistically at par with each other in Mn concentration in straw. All the treatments of nutrient management were significantly higher than control (20.17, 19.76 µg/g). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (37.34, 37.46 µg/g) which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (35.59, 33.65 µg/g). Straw Mn concentration increased by (85.13, 89.57 %) from (20.17, 19.76 µg/g) in control to (37.34, 37.46 µg/g) in $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The increase in manganese concentration in straw may be due to the combined and synergistic effect of increased dose of nitrogen as top-dressing before heading and foliar application of Mn. Similar results were reported earlier (8).

**Effect on grain manganese uptake**

The perusal of data in Table 3, shows that Mn uptake in grain was statistically at par with all the three varieties during both years of study. All the treatments of nutrient management were significantly higher than control (74.95, 82.09 µg/g). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (203.33, 204.50 µg/g) which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (192.34, 188.50 µg/g) which was significantly higher than all other treatments. The significant effect of foliar application of Mn is apparently visible with comparison of $T_2$: NPK+Mn (f) with NPK control. Grain Mn uptake increased by (108.70, 73.65 %) from (74.95, 82.09 g/ha) in control to (156.42, 142.55 g/ha) for $T_2$: NPK+Mn (f). Grain Mn uptake increased by (124.55, 107.75 %) from (74.95, 82.09 g/ha) in control to (168.30, 170.55 g/ha) for $T_5$: NPK+$N_{50}$+Mn (f). Grain Mn uptake increased by (171.29, 129.63 %) from (74.95, 82.09 g/ha) in control to (203.33, 204.50 g/ha) under the treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The increase in grain manganese uptake may be due to the synergistic effect due to application of increased dose of nitrogen as top-dressing before heading and foliar application of Mn. Similar results were reported earlier (8).

**Effect on straw manganese uptake**

The perusal of data in Table 3 reflects that wheat varieties were statistically at par with each other for Mn uptake in straw in the first year but differed significantly in the second year.

During both years of study, in the treatments of nutrient management of Mn uptake in straw, all the treatments were significantly higher than control (91.21, 104.31 g/ha). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (285.99, 283.98 g/ha) which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (256.71, 257.25 g/ha) and all other treatments. Mn uptake

in straw increased by (213.55, 172.25 %) from (91.21, 104.31 g/ha) in control to (285.99, 283.98 g/ha) under treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Similar trends were observed for total Mn uptake in crop. Total Mn uptake in crop increased by (194.49, 163.17 %) from (166.16, 186.40 g/ha) in control to (489.32, 490.55 g/ha) in $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The increase in manganese uptake in straw may be due to the combined and synergistic effect of increased dose of nitrogen as top-dressing before heading and foliar application of Mn. Similar results were reported earlier (8).

**Effect on grain copper concentration**

The perusal of data in Table 2 indicates that all the three varieties were statistically different in grain concentration during both years of study. The highest value of grain Cu concentration was recorded by variety PBW 550 (4.72, 4.03 µg/g) which was statistically at par with HD 2967 (4.65, 4.01 µg/g) but both of these varieties were significantly higher than variety PBW 621 (4.24, 3.72 µg/g). This might be due to the reason that these wheat varieties are responsive to the application of copper.

All the treatments of nutrient management, (except $T_2$: NPK + Mn (f) (3.82, 3.10 µg/g) were significantly higher than control (3.40, 2.99 µg/g). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (5.92, 5.82 µg/g) which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (5.39, 5.62 µg/g) which was significantly higher than all other treatments. The significant effect of foliar application of Cu is apparently visible with comparison of $T_3$: NPK+Cu (f) with NPK control. Grain Cu concentration significantly increased due to foliar application of copper by (26.76, 18.73 %) from (3.40, 2.99 µg/g) in control to (4.31, 3.55 µg/g) for $T_3$: NPK+Cu (f). Grain Cu concentration increased by (44.71, 38.80 %) from (3.40, 2.99 µg/g) in control to (4.92, 4.15 µg/g) for $T_6$: NPK + $N_{50}$ + Cu (f). Grain Cu concentration increased by (74.12, 94.65 %) from (3.40, 2.99 µg/g) in control to (5.92, 5.82 µg/g) for treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The increase in grain Cu concentration may be due to the synergistic effect of increased dose of nitrogen and foliar application of Cu. Similar results were reported earlier also (8)

**Effect on straw copper concentration**

The perusal of data in Table 2. shows that all the three varieties proved statistically different in grain concentration during both years of study. The highest value of straw Cu concentration was recorded by PBW 550 (3.88, 3.08 µg/g) which was statistically at par with HD 2967 (3.80, 3.06 µg/g) but both of these varieties were significantly higher than PBW 621 (3.25, 2.77 µg/g). This might be due to the reason that these wheat varieties are responsive to the application of copper.

All the treatments of nutrient management were significantly higher than control (2.41, 2.02 µg/g). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (5.60, 4.88 µg/g) which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (4.40, 3.67 µg/g) which was significantly higher than all other treatments. Straw Cu concentration increased by (132.37, 141.58 %) from (2.41, 2.02 µg/g) in control to (5.60, 4.88 µg/g) in $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f).

**Effect on Cu uptake in grain and straw**

The perusal of data in Table 3 That among varieities, Cu uptake in grain was significantly different in all the three varieties during both years of study. Highest Cu uptake in grain was in variety PBW 550 (21.92, 18.98 g/ha) which was at par with HD 2967 (21.39, 18.00 g/ha). Both of these varieties were significantly superior to PBW 621 (18.95, 16.86 g/ha).

Among wheat varieties, copper uptake in straw was statistically at par with the three bread wheat varieties in the first year but the varieties differed significantly in the second year. During the year 2012-13, the highest Cu uptake in straw was in HD 2967 (21.37 g/ha) which was significantly higher than both PBW 550 (19.49 g/ha) and PBW 621 (19.95 g/ha). PBW 550 was statistically at par with HD 2967. For wheat variety PBW 550 total Cu uptake in crop was (45.60, 38.47 g/ha), which was statistically at par with HD 2967 (45.35, 39.37 g/ha). Both PBW 550 and HD 2967 were significantly higher than PBW 621 (40.84, 36.81 g/ha).

All the treatments of nutrient management for Cu uptake in straw were significantly higher than control (91.21, 104.31 g/ha). The best treatment was $T_7$: NPK + N50 + Mn (f) + Cu (f) (42.89, 37.00 g/ha), which was significantly higher than all other treatments. Similar trends were observed for total Cu uptake in crop. The significant effect of foliar application of Cu is apparently visible with comparison of $T_3$: NPK+Cu (f) with NPK control. Grain Cu uptake increased by (84.22, 59.05 %) from (9.95, 9.72 g/ha) in control to (18.33, 15.46 g/ha). Grain Cu uptake increased by (21.17, 21.35 %) from (18.33, 15.46 g/ha) in control to (22.21, 18.76 g/ha) for $T_6$: NPK + $N_{50}$ + Cu (f). Grain Cu uptake increased by (222.21, 221.60 %) from (9.95, 9.72 g/ha) in control to (32.06, 31.26 g/ha) for treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). The increase in grain Cu uptake may be due to the synergistic effect of increased dose of nitrogen and foliar application of Cu. Similar results were reported earlier also (8).

**Effect on grain nitrogen content**

The perusal of data in Table 4 shows that nitrogen content in grain was significantly higher in the variety PBW 550 (1.86, 1.80 %) which was significantly higher than PBW 621 (1.77, 1.82 %). Wheat variety PBW 621 was significantly higher than HD 2967 (1.72, 1.76 %) during both years of study.

Grain N content was significantly superior in all the nutrient management treatments than control (1.73, 1.78 %). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (1.85, 1.89 %) which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (1.82, 1.87 %). Grain N content increased by (6.94, 6.18 %) from (1.73, 1.78 %) in control to (1.85, 1.89 %) in $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) for both years of study. This may be due to the reason that due to the increased availability of N in the soil enhanced the uptake and N content in straw.

**Effect on straw nitrogen content**

The perusal of data in Table 4 shows that straw N content among varieties differed significantly. Straw N content was significantly higher in the variety PBW 550 (0.56, 0.58 %) which was significantly higher than HD 2967 (0.45, 0.48 %), which was statistically at par with PBW 621 (0.51, 0.54 %) during both years of study.

Straw N content was significantly superior in all the nutrient management treatments than control (0.44, 0.48 %) The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (0.58, 0.61 %) which was significantly higher than $T_4$: NPK + Mn (f) + Cu (f) (0.55, 0.58 %). Straw N content increased by (31.82, 27.08 %) from (0.44, 0.48 %) in control to (0.58, 0.61 %) in $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) for both years of study. This may be due to the reason that due to the increased availability of N in the soil enhanced the uptake and N content in straw.

**Effect on grain N uptake**

The data on nitrogen uptake by grain and straw and total N uptake in crop have been presented in Table 4**.** Grain N uptake differed significantly among varieties for both years of study. Grain N uptake by the variety PBW 550 grain (86.40, 88.13 kg/ha) was significantly higher than all other varieties, which was statistically at par among varieties HD 2967 (79.14, 79.02 kg/ha) and PBW 621 (79.10, 82.48 kg/ha).

The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (100.10, 100.50 kg/ha) which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (95.83, 96.74 kg/ha) which was statistically at par with $T_5$: NPK + $N_{50}$ + Mn (f) (87.17, 89.82 kg/ha) and $T_2$: NPK + Mn (f) (84.20, 81.32 kg/ha). $T_2$ was statistically at par with $T_6$: NPK + $N_{50}$ + Cu (f) (79.45, 81.25 kg/ha). Grain N uptake increased by (97.79, 42.63 %) from control values (50.61, 57.87 kg/ha) to (100.10, 100.50 kg/ha) under $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Similar effects of treatments of nutrient management on nitrogen uptake were also reported earlier in which nitrogen uptake increased with elevated nitrogen levels (16).

**Effect on straw N uptake**

The perusal of data in Table 4 shows that all the three varieties were significantly different from each other for straw N uptake. The highest value of straw N uptake was recorded by recorded by wheat variety PBW 550 (34.18, 36.70 kg/ha) which was statistically at par with PBW 621 (34.35, 38.90 kg/ha), but both of these varieties were significantly higher than HD 2967 (28.38, 33.52 kg/ha) during both years of study.

All the treatments of nutrient management were significantly higher than control (19.90, 25.34 kg/ha). The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (44.42, 46.24 kg/ha) which was significantly higher than all other treatments. Straw N uptake increased by (123.22, 82.48 %). This may be due to the reason that due to the increased availability of N in the soil enhanced the uptake and N content in straw.

**Effect on total N uptake by crop**

The data on total N uptake in crop have been presented in Table 4**.** Total N uptake differed significantly among varieties for both years of study. Total N uptake by the variety PBW 550 (120.58, 124.83 kg/ha) was significantly higher than PBW 621 (113.45, 121.38 kg/ha) and H D 2967 (107.51, 112.54 kg/ha).

The best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (144.60, 147.76 kg/ha) which was statistically at par with $T_4$: NPK + Mn (f) + Cu (f) (135.50, 141.08 kg/ha), which was significantly higher than all other treatments. Total N uptake increased by (105.08, 77.57 %) from control values (70.51, 83.21 kg/ha) to (144.60, 147.76 kg/ha) under $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). This may be attributed to the reason that due to the increased availability of N in the soil by application of N as top dressing enhanced the uptake and N content in crop. The delayed application of N resulted in continuous supply in N for the longer period of time. Similar effects of treatments of nutrient management on nitrogen uptake were also reported earlier in which nitrogen uptake increased with elevated nitrogen levels (16).

**Interaction effect on N content in straw**

Interaction effect of wheat varieties and nitrogen levels on nitrogen content and uptake in grain and total N uptake by crop was found to be non-significant. However, the interaction effect of N content in straw and its uptake was found to be significant as presented in Table 5.

The interaction values indicated that the highest values of N content in straw ( %) were reported in the combination of treatment $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) and variety PBW 550 (0.64, 0.66 %), which was significantly higher than treatment combinations of $T_7$ with varieties PBW 550 and HD 2967. The 2$^{nd}$ highest values were reported for the combination of $T_7$ and variety PBW 621 (0.59, 0.63 %) which was significantly superior to combination of treatments $T_7$

and variety HD 2967 (0.51, 0.53 %). For all the three varieties, the best treatment was $T_{7.}$ The lowest values of N content in straw ( %) were reported in the combination of control treatment $T_1$: NPK and variety HD 2967 (0.41, 0.44 %) which was significantly inferior to combination of control treatment and varietyPBW 621 (0.44, 0.48 %) which was significantly inferior to combination of control treatment and variety PBW 550 (0.47, 0.51 %).

**Interaction effect on N uptake in straw**

The perusal of data in Table 6 shows that the interaction values indicated the highest of straw N uptake were in the combination of $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f) (51.47, 54.50 kg/ha) and variety PBW 550 which proved significantly better than the combination of $T_7$ and PBW 621 (48.59, 52.94 kg/ha) which was statistically better than the combimation of HD 2967 (37.35, 42.70 kg/ha) and $T_{7.}$ The lowest values of straw N uptake were reported in combination of treatment control and variety HD 2967 (16.10, 20.99 kg/ha) which was significantly inferior to combination of treatment control and variety PBW 621 (23.24, 25.99 kg/ha) which was significantly inferior to combination of treatment control and variety PBW 550 (26.94, 28.64 kg/ha).

**Conclusions**

Among varieties, PBW 550 recorded the highest grain and straw yield, maximum N content, uptake in grain, straw and crop, which were significantly better than varieties PBW 621 and HD 2967 during both years of study. Wheat variety PBW 550 recorded the maximum zinc and iron concentrations and uptakes in grain and straw. Among the treatments of nutrient management, the best treatment was $T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f), which had maximum increasing effects on straw and grain yield, N content, zinc and iron concentrations and their uptake in grain, straw and crop.

It can be concluded from this experiment that increased dose of nitrogen due to application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing (80 DAS) combined with foliar applications of Mn (0.5 %) and Cu (0.2 %) at mid-boot, pre-milk and dough stages enhanced nutrient uptake of N, Cu and Mn thereby causing improvement in yield and mineral enrichment of the wheat grains. Agronomic biofortification is indeed the key for increase in productivity, nutrient uptake and mineral-densing of wheat grains.

**Table 3. Nutrient uptake as influenced by wheat varieties and nutrient management**

| Treatment | Nutrient Uptake (g/ha) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Manganese | | | | | | Copper | | | | | |
| | Grain | | Straw | | Total | | Grain | | Straw | | Total | |
| | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 | 2011-12 | 2012-13 |
| **Varieties (V)** | | | | | | | | | | | | |
| $V_1$: HD 2967 | 148.79 | 143.09 | 189.12 | 197.20 | 337.90 | 340.29 | 21.39 | 18.00 | 23.96 | 21.37 | 45.35 | 39.37 |
| $V_2$: PBW 621 | 144.69 | 140.50 | 193.26 | 198.59 | 337.95 | 339.09 | 18.95 | 16.86 | 21.89 | 19.95 | 40.84 | 36.81 |
| $V_3$: PBW 550 | 147.89 | 142.17 | 168.35 | 166.68 | 316.24 | 308.85 | 21.92 | 18.98 | 23.68 | 19.49 | 45.60 | 38.47 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **11.79** | **NS** | **20.50** | **2.95** | **1.00** | **NS** | **1.75** | **4.53** | **1.52** |
| **Nutrient management (N)** | | | | | | | | | | | | |
| $T_1$: NPK | 74.95 | 82.09 | 91.21 | 104.31 | 166.16 | 186.40 | 9.95 | 9.72 | 10.89 | 10.66 | 20.84 | 20.38 |
| $T_2$: NPK+Mn(f) | 156.42 | 142.55 | 192.96 | 188.35 | 349.38 | 330.90 | 18.17 | 13.92 | 18.23 | 14.87 | 36.4 | 28.79 |
| $T_3$: NPK+Cu(f) | 118.73 | 117.34 | 143.15 | 151.67 | 261.88 | 269.01 | 18.33 | 15.46 | 19.44 | 17.46 | 37.77 | 32.92 |
| $T_4$: NPK+Mn (f)+Cu (f) | 192.34 | 188.50 | 256.71 | 257.25 | 449.05 | 445.76 | 28.38 | 29.07 | 31.73 | 28.09 | 60.11 | 57.16 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 168.30 | 170.55 | 192.83 | 192.59 | 361.13 | 363.14 | 19.53 | 15.37 | 20.09 | 16.05 | 39.62 | 31.42 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 141.20 | 123.73 | 157.46 | 158.15 | 298.66 | 281.88 | 22.21 | 18.76 | 23.93 | 21.44 | 46.14 | 64.90 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 203.33 | 204.50 | 285.99 | 283.98 | 489.32 | 490.55 | 32.06 | 31.26 | 42.89 | 37.00 | 74.95 | 68.26 |
| **LSD (p=0.05) : N** | **23.60** | **16.34** | **27.59** | **19.06** | **49.74** | **34.57** | **2.91** | **1.73** | **3.50** | **2.75** | **5.97** | **5.90** |
| **V × N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 4. Effect of wheat varieties and nutrient applications on nitrogen content and uptake in grain, straw and crop | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nitrogen (grains)** | | | | **Nitrogen (straw)** | | | | **Total N uptake crop (kg/ha)** | |
| | **Content ( %)** | | **Uptake (kg/ha)** | | **Content ( %)** | | **Uptake (kg/ha)** | | | |
| | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** | **2011-12** | **2012-13** |
| **Varieties (V)** | | | | | | | | | | |
| $V_1$: HD 2967 | 1.72 | 1.76 | 79.14 | 79.02 | 0.45 | 0.47 | 28.38 | 33.52 | 107.51 | 112.54 |
| $V_2$: PBW 621 | 1.77 | 1.82 | 79.10 | 82.48 | 0.51 | 0.54 | 34.35 | 38.90 | 113.45 | 121.38 |
| $V_3$: PBW 550 | 1.86 | 1.89 | 86.40 | 88.13 | 0.56 | 0.58 | 34.18 | 36.70 | 120.58 | 124.83 |
| **LSD (p=0.05)** | **0.03** | **0.04** | **NS** | **5.74** | **0.05** | **0.07** | **2.94** | **1.75** | **7.79** | **6.79** |
| **Nutrient management (N)** | | | | | | | | | | |
| $T_1$: NPK | 1.73 | 1.78 | 50.61 | 57.87 | 0.44 | 0.48 | 19.90 | 25.34 | 70.51 | 83.21 |
| $T_2$: NPK+Mn(f) | 1.77 | 1.81 | 84.20 | 81.32 | 0.50 | 0.53 | 33.40 | 36.69 | 117.60 | 118.00 |
| $T_3$: NPK+Cu(f) | 1.75 | 1.79 | 74.42 | 75.91 | 0.46 | 0.49 | 26.94 | 32.91 | 101.36 | 108.82 |
| $T_4$: NPK+Mn (f)+Cu (f) | 1.82 | 1.87 | 95.83 | 96.74 | 0.55 | 0.58 | 39.67 | 44.34 | 135.50 | 141.08 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 1.79 | 1.84 | 87.17 | 89.82 | 0.53 | 0.55 | 35.27 | 38.59 | 122.43 | 128.40 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 1.76 | 1.81 | 79.45 | 81.85 | 0.49 | 0.51 | 29.84 | 34.19 | 109.28 | 116.04 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 1.85 | 1.89 | 100.10 | 101.50 | 0.58 | 0.61 | 44.42 | 46.24 | 144.60 | 147.76 |
| **LSD (p=0.05) : N** | **0.01** | **0.01** | **10.51** | **7.04** | **0.01** | **0.01** | **0.71** | **0.76** | **10.61** | **6.85** |
| **V × N** | **NS** | **NS** | **NS** | **NS** | **0.01** | **0.02** | **1.22** | **1.32** | **NS** | **NS** |

| Table 5. Interaction effect of varieties and nutrient management on N content in straw ( %) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 0.41 | 0.44 | 0.47 | 0.44 | 0.48 | 0.51 |
| $T_2$: NPK+Mn (f) | 0.44 | 0.51 | 0.54 | 0.47 | 0.54 | 0.57 |
| $T_3$: NPK+Cu (f) | 0.42 | 0.45 | 0.51 | 0.45 | 0.49 | 0.53 |
| $T_4$: NPK+Mn (f)+Cu (f) | 0.47 | 0.56 | 0.61 | 0.51 | 0.59 | 0.63 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 0.45 | 0.54 | 0.59 | 0.49 | 0.57 | 0.60 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 0.43 | 0.48 | 0.55 | 0.46 | 0.51 | 0.55 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 0.51 | 0.59 | 0.64 | 0.53 | 0.63 | 0.66 |
| **LSD (p=0.05)** | **V × N = 0.01** | | | **V × N = 0.02** | | |

| Table 6. Interaction effect of varieties and nutrient management on N uptake in wheat straw (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 16.10 | 23.24 | 26.94 | 20.99 | 25.99 | 28.64 |
| $T_2$: NPK+Mn (f) | 31.13 | 39.48 | 35.24 | 31.83 | 41.03 | 36.40 |
| $T_3$: NPK+Cu (f) | 29.42 | 27.91 | 28.53 | 32.11 | 33.69 | 32.46 |
| $T_4$: NPK+Mn (f)+Cu (f) | 36.56 | 47.44 | 41.00 | 39.54 | 45.33 | 47.17 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 34.01 | 39.17 | 37.37 | 35.02 | 41.16 | 40.01 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 28.83 | 32.55 | 30.97 | 32.23 | 36.14 | 32.78 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 37.35 | 48.59 | 51.47 | 42.70 | 52.94 | 54.50 |
| **LSD (p=0.05)** | **V × N = 1.22** | | | **V × N = 1.32** | | |

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**CHAPTER 4**

## GENERAL DISCUSSION

**EXPERIMENT: Impact of nitrogen, zinc and iron on growth, productivity, agronomic biofortification and quality of wheat.**

### 4.1 Biometrical/ growth observations:

#### 4.1.1 Emergence count

The data given in Annexure XIV, Table 1 showed that various varieties, nutrient treatments and their interactions did not show any significant difference. It indicated that plant population was uniform in all the plots.

#### 4.1.2 Periodic plant height (cm)

Plant height is an index of plant development which gives an idea of estimated biomass production and crop yield. The perusal of data related to plant height signifies a progressive increase in plant height with the advancement in crop age (Annexure XIV, Table 2).

The plant height at 60 DAS was not significantly affected by varieties and nutrient treatments. Wheat variety PBW 550 (72.3, 69.5 cm) was significantly superior in height than both varieties PBW 621(50.6, 48.2 cm) and HD 2967 (48.1, 46.9 cm) at 90 DAS. The varieties PBW 621 and HD 2967 were statistically at par with each other in height at 90, 120 DAS and at harvest but significantly superior to variety PBW 550.

All nutrient treatments were statistically significant in height than control at all the stages except at 60 DAS. At 90 DAS, $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (62.8, 61.0 cm) was the best treatment, which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f) (61.3, 59.3 cm) and $T_7$: NPK+$N_{50}$+Zn (f) (61.0, 58.8 cm) but significantly higher than $T_6$: NPK+Zn (s)+$N_{50}$ (58.8, 56.6 cm). The increase in plant height (after 60 DAS) is attributed to the physiological role of N, Zn and Fe in plant metabolism and growth and higher photo-synthetic activity. Cells developed with elevated level of N tend to be large and having higher meristematic activity and formation of protoplasm which increases the plant growth (Havlin *et al* 2010).

#### 4.1.3 Dry matter accumulation (q/ha)

The dry matter accumulation increased consistently during the growth period (Annexure XIV, Table 3). Wheat varieties showed significant effect on dry matter accumulation at 90 and 120 DAS (except 60 DAS, at which treatment effect was non-significant). At 90 DAS, PBW 550 (62.2, 57.4 q/ha) produced significantly higher dry matter than PBW 621 (45.6, 42.2 q/ha). PBW 621 accumulated significantly higher than HD 2967 (36.7, 33.1 q/ha). At 120 DAS, PBW 550 (115.6, 108.4 q/ha) produced significantly lower dry matter than PBW 621 (122.8, 117.2 q/ha). PBW 621 was statistically at par with variety

HD 2967 (120.4, 115.1 q/ha). The differences in dry matter accumulation were due to differential increase in vegetative growth rate of these varieties (Ram *et al* 2012).

In the treatments of nutrient management, $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (55.7, 52.6 q/ha) was the best treatment which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f) (50.1, 48.3 q/ha) at 90 DAS. The treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (136.8, 131.3 q/ha) was the best treatment which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f) (123.8, 125.1 q/ha) at 120 DAS also. The treatment $T_4$ was significantly higher than all other remaining treatments.

This may be attributed to the reason that apart from role of N in boosting plant growth, soil and foliar application of Zn effectively increased dry matter production of wheat plants. These results are in accordance to those of Imtiaz *et al* (2003), Ozokutlu *et al* (2006) and Ranjbar and Bahmaniar (2007).

**4.1.4 Periodic leaf area index (LAI)**

LAI is an important indicator of crop growth. Higher the LAI, higher will be PAR interception which is the source of energy for the process of photosynthesis and consequently leading to higher biomass accumulation by crop (Annexure XIV, Table 4).

LAI differed significantly at 90 and 120 DAS, but not at 60 DAS. However, at 90 and 120 DAS variety PBW 550 recorded significantly lower LAI than PBW 621 which was significantly higher than HD 2967. This might be due to differential ability of wheat varieties in LAI and shy tillering habit of PBW 550 (Ram *et al* 2012, Hussain *et al* 2012).

The nutrient management treatments had significant effect on LAI at 90 and 120 DAS (except 60 DAS) during both years. Treatment $T_8$ [NPK+Zn (s)+$N_{50}$+Zn (f)] recorded significantly higher LAI than all the treatments. All treatments were significantly higher than control. The second best treatment was $T_4$ [NPK+Zn (s)+Zn (f)].

This might be due to the reason that vegetative growth resulting due to soil application of zinc sulphate caused higher photosynthetic activities which were further boosted by additional dose of N @ 50 kg/ha (applied before heading) and its synergistic effect with foliar application of Zn. These results are in line of those reported by Salvagiotti and Miralles (2008) and Nadim *et al* (2012) related to increase in LAI due to application of N before anthesis and soil application of zinc sulphate.

**4.1.5 Periodic tiller count**

Tillering is another important factor in wheat. The tillering stage in wheat generally comes at 40-45 DAS which finally leads to higher ear production and increase in yield. The data on periodic tiller count recorded at 60, 90, 120 DAS and at harvest have been presented in Annexure XIV, Table 5.

During both years, PBW 621 had highest tiller count followed by HD 2967 followed by PBW 550 at all the growth stages. At 60, 90,120 DAS, PBW 621 and HD 2967 were statistically at par with each other. PBW 621 was significantly higher than PBW 550. At harvest, both varieties PBW 621 and HD 2967 were statistically at par with each other, but significantly higher than variety PBW 550.

Among the treatments of nutrient management, at 60 DAS, Treatments $T_1$: NPK Control, $T_3$: NPK+Zn (f), $T_5$: NPK+Fe (f), $T_7$: NPK+$N_{50}$+Zn (f) and $T_9$: NPK+$N_{50}$+Fe (f) were statistically at par with each other and treatments $T_2$: NPK+Zn (s), $T_4$: NPK+Zn (f)+Zn (s), $T_6$: NPK+Zn (s)+$N_{50}$ and $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) were statistically at par with each other. Latter set of treatments was significantly higher than former one. This may be due to the promotive effect of soil application of $ZnSO_4$ on tillering. Khan *et al* (2008) too advocated the increasing effect of soil application of Zn on tillering in wheat A consistent increase in tiller count was observed till 90 DAS. The maximum tillers were produced at 90 DAS with the treatment $T_8$ [NPK+Zn (s)+$N_{50}$+Zn (f)] (401, 397 tillers/$m^2$) which were significantly higher than all other treatments. This may be attributed to the synergistic effect of Zn and N on tillering. Improved supply of nutrients induced higher tillering as compared to lower N status and other micronutrients. Rahman *et al* (2002) also reported that N application had tremendous effect on formation and survival of tillers. Under treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f), at 120 DAS (394, 390 tillers/$m^{2)}$ and at harvest (389, 384 tillers/$m^2$), tiller count/$m^2$ decreased in comparison to 90 DAS.

The enhancement in tiller number with increase in nitrogen availability is attributed to the rapid conversion of carbohydrates in to proteins and consequent increase in number and size of growing cells which ultimately resulted in increased number of tillers. These findings are in line with those of Singh and Aggarwal (2001).

**4.2 YIELD ATTRIBUTES**

**4.2.1 Effective tillers at harvest**

The effective tillers/$m^2$ are the main yield components. The data on the effective tillers/$m^2$ are presented in Annexure XIV, Table 6**.**

Among wheat varieties, PBW 621(329, 326 tillers/$m^2$) produced the highest effective tillers, which was significantly higher than PBW 550 (315, 309 tillers/$m^2$) but statistically at par with HD 2967 (325, 321 tillers/$m^2$).

All the the treatments of nutrient were significantly higher than control (288, 277 tillers/$m^2$). The maximum effective tillers were produced with the combined treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (386, 382 tillers/$m^2$) which was significantly higher than $T_4$ [NPK+Zn (s)+Zn (f)] (370, 366 tillers/$m^2$) which was significantly higher than all other treatments.

The increased effective tillers/$m^2$ with higher dose of N is due to the stimulatory effect of N on tillering through cytokinin-synthesis resulting into more number of effective tillers/$m^2$ (Gardner *et al* 1988). Semi-dwarf varieties due to higher exploitation of assimilates to the ear during pre-flowering period result in higher number of fertile tillers/$m^2$ and more fertile florets (Calderini *et al* 1995, Miralles *et al* 1988). Zinc sulphate also increased the total number of fertile tillers/$m^2$ (Khan *et al* 2008). Iron being part of photosynthetic machinery also contributed to enhanced photo-synthesis and generation of crop biomass (Havlin *et al* 2010).

**4.2.2 Ear length (cm)**

Ear length indicates the number of spikelets which in turn affects the number of grains. Much of the ear differentiation and development will depend upon the availability of carbohydrates when there is competition with strong sinks like tillers, leaf and stem (Reddy 2004).

The data is presented in Annexure XIV, Table 6, variety PBW 550 (10.8, 10.7 cm) produced the highest ear length which was significantly higher than PBW 621 (10.3, 10.1cm) and HD 2967 (10.1, 9.8 cm). The varieties PBW 621 and HD 2967 were statistically at par with each other for ear length.

All the treatments of nutrient management were significantly higher than control (9.4, 9.3 cm). $T_8$: NPK+Zn (s)+$N_{50}$ + Zn (f) was the best treatment (11.2, 11.0 cm), which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f) (11.2, 10.7 cm) which was significantly higher than all other treatments. Similar results were reported by Rao (1981) and Khan *et al* (2008) who reported the increase in spike length with increasing level of N and soil application of zinc sulphate.

**4.2.3 Grains/ear**

The number of grains/ear is an important component of grain yield. Grains/ear is the product of spikelets/ear and grains/spikelets. The sink capacity of grain is the product of number of grains set and growth characteristics of individual grains (Reddy 2004). The data of number of grains/ear are presented in Annexure XIV, Table 6**.**

Among the wheat varieties, the wheat variety PBW 550 (45.6, 44.2) produced the highest number of grains/ear which was significantly higher than PBW 621 (42.0, 40.5) and HD 2967 (39.4, 38.1). The varieties PBW 621 and HD 2967 were statistically at par with number of grains/ear.

All the treatments of nutrient management were significantly higher than control (39.9, 39.0). $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment (44.9, 43.0), which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f) (44.1, 42.8) which was significantly higher than all other treatments. Adequate N might have increased the grains/ear by preventing the

degradation of spikelets at the time of grain development. The increased number of spikelets led to incremental increases in spike length. Similar results related to improvement in spike length, effective tillers/plant and number of grains/plant by zinc application have been reported by Reddy and Bhardwaj (1989), Islam *et al* (1999) and Genc *et al* (2006).

**4.2.4 Thousand grain weight (g)**

Thousand grain weight is a reliable index of seed development, plumpness, grain quality and crop yield. The data is presented in Annexure XIV, Table 6.

Out of the three varieties, the wheat variety PBW 550 (45.5, 44.0 g) produced the highest number of grains/ ear which was significantly higher than PBW 621 (42.9, 41.2 g) and HD 2967 (42.1, 40.8 g). All three varieties were statistically at par with each other for thousand grain weight. Jadhav and Karanjikar (2001) reported the similar results.

All the treatments of nutrient management were significantly higher than control (38.4, 37.2 g). $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment (47.7, 44.2 g) which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f) (46.6, 45.0 g) which was significantly higher than all other treatments except $T_7$: NPK+$N_{50}$+Zn (f) (43.0, 41.8 g). The three components of grain yield, fertile tillers/m, grains/ear and thousand grain weight all increased with zinc sulphate application (Anexure XI). This may be attributed to the synergistic effect of N and Zn/Fe. Khan *et al* (2008) also reported the similar increasing effect of zinc sulphate on thousand grain weight.

**4.2.5 Grain yield (q/ha)**

The grain yield of a crop is the net result of interaction of various factors and is a valid criterion for comparing the efficacy of various treatments. The data on grain yield is presented in Annexure XIV, Table 7.

The wheat variety PBW 550 (51.34, 48.47 q/ha) produced the highest grain yield which was significantly higher than HD 2967 (45.6, 44.42 q/ha). The varieties PBW 550 and PBW 621 (47.41, 48.95 q/ha) were statistically at par with each other in grain yield. Ram *et al* (2012) reported the similar results on varietal performance.

All the treatments of nutrient management were significantly higher than control (36.11, 33.07 q/ha). $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment (55.85, 56.53 q/ha),which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f). The treatment $T_4$ was statistically at par with $T_7$: NPK+$N_{50}$+Zn (f) and $T_6$: NPK+$N_{50}$+Zn (s).

The significant effect of soil/foliar application of Zn and Fe on grain yield is apparently visible with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_5$: NPK+Fe (f) with NPK control. Grain yield increased by (32.82, 38.07 %) from (36.11, 33.07 q/ha) in control to (47.96, 45.66 q/ha) for $T_2$: NPK+Zn (s) by. Grain yield increased by (38.44, 44.57 %) from (36.11, 33.07 q/ha) in control to (49.99, 47.81 q/ha) for $T_3$: NPK+Zn (f). Grain yield

increased by (43.34, 62.84 %) from (36.11, 33.07 q/ha) in control to (51.76, 53.85 q/ha) for treatment $T_4$: NPK+Zn (s)+Zn (f). Grain yield increased by (21.38, 26.04 %) from (36.11, 33.07 q/ha) in control to (43.83, 41.68 q/ha) for treatment $T_5$: NPK+Fe (f). Grain yield has increased by (54.67, 70.94 %) from (36.11, 33.07 q/ha) in control to (55.85, 56.53 q/ha) for the best treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f).

Zn increased membrane-integrity, heat-tolerance, synthesis of carbohydrates, cytochrome and nucleotide synthesis, auxin-synthesis, chlorophyll synthesis and metabolism of N (Marschner *et al* 1996) thereby enhancing photo-synthesis, photosynthates, their translocation to grain and finally crop yield in the treatments $T_2$: NPK+Zn (s), $T_3$: NPK+Zn (f), $T_4$: NPK+Zn (s)+Zn (f), $T_6$: NPK+$N_{50}$+Zn (s),$T_7$: NPK+$N_{50}$+Zn (f) and $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (Annexure XIV, Table 7). Iron being structural component of cytochromes, hematin and ferrichrome promoted redox reactions in respiration and photosynthesis (Marschner *et al* 1996) and increased yield in their respective treatment $T_5$: NPK+Fe (f) and $T_9$: NPK+$N_{50}$+Fe (f) (Annexure XIV, Table 7). The increase in grain yield was further due to the cumulative effect of increase in all the yield components such as effective tillers/$m^2$, number of grains/ear, spike length and thousand grain weight (Annexure XIV, Table 7). Similar results related to increase in grain yield due to synergistic effect of N and Zn by soil and foliar application of Zn have been reported by Narwal *et al* (2010), Kutman *et al* (2010), Shi *et al* (2010) and Jan *et al* (2013).

The interaction effects between varieties and treatments of nutrient management were non-significant (Annexure XIV, Table 8).

**4.2.6 Straw yield (q/ha)**

Straw yield also makes important contribution to the overall crop value as it is used as a feed for the cattle. The straw yield is presented in Annexure XIV, Table 7. Ram *et al* (2012) reported the similar results on varietal performance.

Among the wheat varieties, the wheat variety PBW 550 (63.19, 58.85q/ha) produced the lowest straw yield which was significantly inferior to PBW 621(74.37, 67.23 q/ha). The varieties PBW 621 and HD 2967 (73.31, 69.51 q/ha) were statistically at par with each other for grain yield.

All the treatments of nutrient management were significantly higher than control (64.46, 55.41q/ha) except $T_2$: NPK+Zn (s) (68.47, 63.42). $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment (78.97, 72.93 q/ha), which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f) (70.03, 69.94 q/ha). The treatment $T_4$ was statistically at par with $T_7$: NPK+$N_{50}$+Zn (f), $T_6$: NPK+$N_{50}$+Zn (s) and $T_3$: NPK+Zn (f).

The significant effect of soil/foliar application of Zn and Fe on straw yield is apparently visible with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_5$: NPK+Fe

(f) with NPK control. Straw yield increased by (6.6, 14.46 %) from (64.46, 55.41 q/ha) in control to (68.47, 63.42 q/ha) for $T_2$: NPK+Zn (s). Straw yield increased by (8.97, 19.15 %) from (64.46, 55.41 q/ha) in control to (70.24, 66.02 q/ha) for $T_3$: NPK+Zn (f). Straw yield has increased by (8.64, 26.22 %) from (64.46, 55.41 q/ha) in control to (70.03, 69.94 q/ha) for treatment $T_4$: NPK+Zn (f)+Fe (f). Straw yield has increased by (5.83, 7.65 %) from (64.46, 55.41 q/ha) in control to (68.22, 59.65 q/ha) for treatment $T_5$: NPK+Fe (f). Straw yield has increased by (22.51, 31.62 %) from (64.46, 55.41 q/ha) in control to (78.97, 72.93 q/ha) for the best treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f).

The increase in straw yield was due to the cumulative effect of increase in all the straw yield attributing indices such as plant height, dry matter accumulation and number of tillers (Annexure XIV, Table 7). Similar results related to increase in straw yield due to soil and foliar application of Zn have been reported by Jan *et al* (2013).

**4.2.7 Harvest index**

Harvest index is an important parameter indicating the efficiency in partitioning of dry matter to the economic part of crop. Higher the harvest index, higher is the economic return of the crop. The data regarding harvest index have been presented in Annexure XIV, Table 7.

Among the wheat varieties, PBW 550 (44.83, 45.16) had significantly higher harvest index followed by varieties PBW 621(38.92, 42.13) and HD 2967 (38.35, 38.99). Mughal *et al* (2011) reported that harvest index was maximum in variety Sonam (39.4 %) followed by Kailash (35.6 %), while local check recorded lowest harvest index of 23.5 % only.

All the treatments of nutrient management were significantly higher than control (35.90, 37.38). Treatment $T_8$ [NPK+Zn (s)+$N_{50}$+Zn (f)] (41.43, 43.66) and $T_4$ [NPK+Zn (s)+Zn (f)] (42.50, 43.50) had significantly higher harvest index than control. This might be due to favourable effects of increasing nitrogen, Zn and Fe on growth and yield attributing characters which translated into grain yield.

**4.3 Quality parameters**

**4.3.1 Physical grain characteristics**

**4.3.1.1 Grain appearance score**

The grain appearance score is the measure of the glossiness, colour, size and shape of wheat grains. Grain appearance score is more about aesthetic value of the produce. The grains with good lustre, medium size and oval shape etc. are favoured by end consumer. The grain appearance was given a score on a scale of 0 to 10. The data on grain appearance score have been presented in Annexure XIV, Table 9.

Among the wheat varieties, PBW 550 recorded the highest grain appearance score (5.8, 6.0).

Among nutrient treatments, the results were significantly different. Grain appearance of treatment $T_8$ [NPK+Zn (s)+$N_{50}$+Zn (f)] (6.1, 6.0) and $T_7$: NPK+$N_{50}$+Zn (f) (5.8, 6.0) and $T_6$: NPK+Zn (s)+$N_{50}$ (5.7, 5.9) were statistically at par with each other but significantly higher than $T_4$ [NPK+Zn (s)+Zn (f)] (5.4, 5.6). All these treatments had significantly higher grain appearance score than control (5.1, 5.2). Sardana *et al* (2005) also observed significant increase in grain appearance score by increased level of nitrogen.

**4.3.1.2 Hectolitre weight (kg/hl)**

Hectolitre weight is the specific grain weight which is determined by measurement of weight per unit volume and based on the density, plumpness, size and uniformity of the grains. The results of hectolitre weight are given in Annexure XIV, Table 9. The hectolitre weight values reflect the conditions during the grain filling period of the crop. Any stress during the grain filling period affects the hectolitre weight negatively. The higher hectolitre weight has lots of plumper grains with higher grain density.

The hectolitre weight was comparatively higher during the year 2011-12 than 2012-13 reflecting the harsh growing conditions during the grain ripening period. PBW 550 recorded the highest hectolitre weight (80.4, 79.9 kg/hl) which was significantly higher than PBW 621 (77.5, 76.7 kg/hl), that was statistically at par with HD 2967 (77.2, 76.3 kg/hl).

Under the nutrient treatments the highest values of hectolitre weight (78.9, 78.4 kg/hl) was reported under the treatment $T_8$ [NPK+Zn (s)+$N_{50}$+Zn (f)] (78.9, 78.4 kg/hl) which was statistically at par with the treatment $T_7$: NPK+$N_{50}$+Zn (f) (78.8, 78.3 kg/hl), $T_6$: NPK+Zn (s)+$N_{50}$ (78.4, 77.5 kg/hl), $T_4$: NPK+Zn (s)+ Zn (f) (78.2, 77.5 kg/hl) and $T_3$: NPK+Zn (f) (78.1, 77.4 kg/hl). All of these treatments proved significantly higher than control. hectolitre weight increased with the elevated nitrogen level due to increase in grain density. Kaur *et al* (2006) reported the similar results.

**4.3.1.3 Grain hardness (kg)**

Grain hardness is genetically related to protein content but in Indian wheats it is more of physical nature indicating the protein denaturation due to the harsh ambient temperature during the grain ripening period. The grain hardness is determined by the bonding of starch and protein molecules which is higher at higher level of protein content. The harder grains produce better chapatties due to a higher production of damaged starch during the grinding of whole wheat which in turn raises the water absorption of dough.The contribution of grain hardness alone to the chapatti quality is about 40 % (Mishra *et al* 1998). The results of grain hardness are given in Annexure XIV, Table 10.

The grain hardness values were comparatively higher during the year 2012-13 than 2011-12 reflecting the harsh growing conditions during the grain ripening period. The variety PBW 550 recorded the highest grain hardness (11.8, 12.0 kg) which was significantly higher

than PBW 621 (11.3, 11.6 kg). The wheat variety PBW 621 was statistically higher than HD 2967 (9.6, 10.4 kg) during both the years. Under the nutrient treatments, the highest values of grain hardness (12.4, 12.8 kg) were reported under the treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) which was significantly higher than all the treatments. All the nutrient management treatments were significantly higher than control. Kaur *et al* (2006) also reported that the grain hardness increased with increase in nitrogen level.

### 4.3.2 Chemical grain characteristics

#### 4.3.2.1 Protein content (%)

Protein content in wheat is influenced by nitrogen and micronutrient availability at the grain formation stage and other environmental conditions. Protein content is the main feature of grain quality which imparts vitreousness in grains and determines their end use quality. Protein has two components associated with it, namely the quantity and the quality of protein. Both are affected by the levels of nitrogen and Zn in the plant as it develops through the season. When managing the protein quality, the main aim is to get the plant to produce long chain gluten proteins such as gliadin, glutenin, albumin and globulin, which give wheat products unique extensibility and processing properties.

The data in Annexure XIV, Table 10 shows that among the wheat varieties, the protein content values were significant for all the three varieties for both the years however the highest values of two years for protein content were reported in variety PBW 550 (11.88, 11.94 %) followed by PBW 621 (11.26, 11.33 %) followed by HD 2967 (11.22, 11.23 %).

Under nutrient management treatments, the highest values of protein content (12.44, 12.56 %) were reported under the treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f), which was statistically at par with $T_7$: NPK+$N_{50}$+Zn (f) (12.22, 12.25 %), $T_9$: NPK+$N_{50}$+Fe (f) (11.94, 11.95 %), $T_6$: NPK+Zn (s)+$N_{50}$ (11.60, 11.82 %) and significantly higher than all other treatments.

In the treatments of nutrient management, soil application of Zn followed by top-dressing of nitrogen (just before heading) increased nitrogen use efficiency. N metebolisam was further enhanced with foliar application of Zn. Foliar application of micronutrients in association with N significantly increased amino acid synthesis to increase protein contents in wheat grains as compared to control treatments, which further contributed to increase in grain hardness and sedimentation values also.These results are in tune with findings of Strong (1982), Whest and Cassman (1982), FAO (2006), Sardana *et al* (2005), Shi *et al* (2010) and Zeidan *et al* (2010).

#### 4.3.2.2 SDS-Sedimentation value (cc)

Sedimentation value determines the functional quality of gluten proteins present in the grain. Protein content of grains also affects its sedimentation value which is affected by

availability of nitrogen.

The sedimentation values were comparatively higher for the year 2012-13 in comparisomn to year 2011-12 due to favourable environmental conditions leading to higher filling of grains and lesser damage to the fuctional quality of proteins (Annexure XIV, Table 10).

The highest values of two years for sedimentation values were reported in variety PBW 550 (49, 50 cc) followed by PBW 621 (47, 49 cc) followed by HD 2967 (42, 43 cc). During both years, under nutrient management treatments, the highest values of sedimentation values (51, 53 cc) were reported under the treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) which was statistically at par with $T_7$: NPK+$N_{50}$+Zn (f) (50, 51 cc) which was similar to $T_6$: NPK+Zn (s)+$N_{50}$ (48, 49 cc) which was significantly higher than all other treatments.

These results are in line of protein content. Actually, gluten up to 90 % is constituted by the proteins and the improvement in proteins caused the higher development of gluten and consequently in the improvement in sedimentation values. Similar trend was reported by Mehta *et al* (2006).

**4.3.2.3 β-Carotene (ppm)**

β-carotene is a pigment in wheat grain and imparts a characteristic golden hue to wheat semolina. β -carotene is a precursor of vitamin A thereby it is of nutritional significance also. The β-carotene content recorded in experiment of different treatment combinations is given in the Annexure XIV, Table 10.

Among the wheat varities the highest value of β-carotene ware recorded in HD 2967 (4.98, 5.43 ppm) which was significantly higher than PBW 550 (4.80, 5.23 ppm) which was statistically at par with PBW 621 (4.60, 4.97 ppm) during both years.

All treatments of nutrient management were significantly higher than control. Under nutrient management treatments, the highest values of β-carotene (5.30, 5.81 ppm) were reported under the treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) which was statistically at par with the treatment $T_7$: NPK+$N_{50}$+Zn (f) (5.25, 5.69 ppm) and $T_6$: NPK+Zn (s)+$N_{50}$ (5.20, 5.54 ppm) during both the years.

This might be due to the reason that foliar application of micronutrients in association with N significantly increased amino acid synthesis in the plant cells (leaves) to translocate increased protein in wheat grains (sink) in the nutrient treatments, which further contributed to increase in grain hardness and sedimentation values also. An improvement in the β-carotene content was reported up to a level of 200 kg/ha (Singh *et al* 2002). It is imperative to apply additional dose of nitrogen near reproductive phase for attaining high content of carotene pigments. It is pertinent to mention here that significantly enhanced β-carotene levels in wheat grains will further help in the higher absorption of metal cations like Zn and Fe in

human gut by reducing the anti-nutrient like phytic acid (dephytisation) concentration and decreasing the chelation of metal cations in the wheat grains thereby raising its nutritional value (Vesna *et al* 2013). The interaction effects were non-significant in both the years (Annexure XIV, Table 10).

**4.3.2.4 Phenol Reaction Score**

The Phenol Reaction Score is indicative of the Tyrosinase enzyme activity causing darkening of dough during storage and processing was numerically higher during 2011-12 than 2012-13 due to the milder environment might have facilitated the escape of the enzyme. The lower Phenol Reaction Score value is higher as such dough can be stored for long and the risk of darkening and nutritional losses is minimum.

Phenol Reaction Score was found non-significant in all the three varieties, nutrient treatments and their interaction in both years.

**4.3.3 Effect on grain nitrogen content**

The perusal of data given in Annexure XIV, Table 11 indicates that all the three wheat varieties PBW 550, PBW 621 and HD 2967 were statistically at par with each other for nitrogen content in grain in the 1$^{st}$ year of study. The variety PBW 550 was significantly higher in the variety PBW 550 (1.79 %) which was significantly higher than PBW 621 (1.75 %) and HD 2967 (1.73 %).

Grain N content was significantly superior in all the nutrient management treatments than control. The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f), which was significantly higher than $T_4$: NPK+ +Zn (s)+Zn (f). Grain N content increased by (8.54, 9.52 %) from (1.64, 1.68 %) in control to $T_4$: NPK+ +Zn (s)+Zn (f) (1.78, 1.82 %).Grain N content increased by (8.89, 8.70 %) from (1.64, 1.68 %) in control to $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (1.80, 1.84 %). This may be due to the increased availability of N and stimulation in N metabolism by applications of Zn in the soil or by foliar method, which enhanced N content in grain.These findings are in accordance with Dhaliwal *et al* (2009) and Ziaeian and Malakouti (2001).

The interaction effect of varieties and nutrient management treatments on N content in grain was significant, which has been presented in Annexure XIV, Table 12. The interaction values indicated that the combination of treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) and variety PBW 550 gave the maximum N content in grain (1.82,1.87 %) which was significantly higher than $T_4$: NPK+ +Zn (s)+Zn (f) (1.80,1.85 %) during both years. The lowest N content in grain was recorded in the control treatment and variety HD 2967 (1.59, 1.62 %) which was significantly inferior to combination of control and variety PBW 621 (1.65, 1.68 %). The combination of control treatment $T_1$ and variety 550 was significantly superior to the combinations of control treatment and varieties PBW 621 and HD 2967.

### 4.3.4 Effect on straw nitrogen content

Straw N content was significantly higher in the variety PBW 550 (0.56, 0.60 %) which was significantly higher than PBW 621 (0.51, 0.55 %) and HD 2967 (0.50, 0.54 %). The variety PBW 621 and HD 2967 were statistically at par with each other during both years of study (Annexure XIV, Table 11).

Straw N content was significantly superior in all the nutrient management treatments than control. The best treatment was $T_8$: NPK+Zn(s) +$N_{50}$+Zn (f) (0.63, 0.67 %) which was significantly higher than $T_4$: NPK+ +Zn (s)+Zn (f). Straw N content increased by (39.53, 33.33 %) from (0.43, 0.48 %) in control to (0.60, 0.64 %) in $T_4$: NPK+ +Zn (s)+Zn (f). Straw N content increased by (46.51, 39.58 %) from (0.43, 0.48 %) in control to (0.63, 0.67 %) in $T_8$: NPK+Zn (s)+$N_{50}$+Zn(f). This may be due to the increased availability of N and stimulation in N metabolism by applications of Zn in the soil or by foliar method, which enhanced N content in grain. These findings are in accordance with Dhaliwal *et al* (2009) and Ziaeian and Malakouti (2001).

### 4.3.5 Effect on N uptake in grain, straw and crop

The data on nitrogen uptake by grain and straw with total uptake have been presented in Annexure XIV, Table 11.

Grain N uptake differed significantly in the 1$^{st}$ year among three varieties. PBW 550 (89.32 kg/ha) which was significantly higher than HD 2967 (77.52 kg/ha) but statistically at par with PBW 621 (81.07 kg/ha). Grain N uptake among three varieties was statistically non-significant in the 2$^{nd}$ year.

Straw N uptake was highest in the variety PBW 621(37.93 kg/ha), which was significantly superior to that of variety PBW 550 (35.39, 35.31 kg/ha) in the first year, but statistically at par with variety HD 2967. Straw N uptake was highest in the variety HD 2967 (37.54 kg/ha), which was significantly superior to that of variety PBW 550 (35.31 kg/ha), but statistically at par with varietyPBW 621 in the second year. Total N uptake by crop was statistically non-significant among three varieties during both cropping seasons.

Under nutrient management, all the treatments proved significantly higher than control for uptake in grain, straw and crop. The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) for grain uptake (100.53, 104.02 kg/ha), straw uptake (49.75, 48.86 kg/ha) and total N uptake by crop (150.28, 152.88 kg/ha) which were significantly higher than their respective controls respectively {(59.22, 55.56 kg/ha), (27.72, 26,60 kg/ha), (86.94, 82.15 kg/ha)}. The uptakes in grain, straw and crop for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) increased by (69.76, 87.22 %), (79.47, 83.68 %) and (72.85, 86.10 %) respectively. This increase in N uptake in grain, straw and crop might be due to the synergistic effects of Zn and elevated nitrogen levels.

Similar effects of nitrogen management treatments on nitrogen uptake were also observed by Kumar and Ahlawat (2006) in which nitrogen uptake increased with elevated nitrogen levels.

**4.3.6 Interaction effect of wheat varieties and nutrient treatments on straw N uptake**

The interaction values presented in Annexure XIV, Table 13 indicated that the highest straw N uptake was highest for the combination of treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) and variety PBW 621(55.46 kg/ha) in the first year which was significantly superior to the combinations of both varieties PBW 550 and HD 2967 with treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) . The highest straw N uptake was highest for the combination of treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) and variety HD 2967(52.32 kg/ha) which was significantly superior to the combinations of both varieties PBW 621 and PBW 550 with treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) in the second year. However, the other interaction effects were found to be non-significant.

**4.4 Effect on zinc concentration in grain and straw**

The data given in Annexure XIV, Table 14 indicates that among the wheat varieties, all the three varieties were significant in grain and straw Zn concentration during both years. The highest value of grain Zn concentration (30.38, 29.87 µg/g) was found in variety PBW 550 which was significantly higher than PBW 621 (28.83, 28.67 µg/g) followed by statistically inferior variety HD 2967 (27.07, 26.55 µg/g).

All the treatments of nutrient management were significantly higher than control (23.64, 22.48 µg/g) except $T_5$: NPK+Fe (f) (23.66, 23.65 µg/g) and $T_9$: NPK+$N_{50}$+Fe (f) (24.62, 23.83 µg/g), which were statistically at par with control. The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (36.99, 36.60 µg/g) which was significantly higher than all the treatments. The significant effect of soil/foliar application of Zn on grain yield is apparently visible with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_5$: NPK+Fe (f) with NPK control. Grain Zn concentration increased by (7.15, 10.14 %) from (23.64, 22.48 µg/g) in control to (25.33, 24.76 µg/g) for $T_2$: NPK+Zn (s) by. Zn grain concentration increased by (24.37, 29.49 %) from (23.64, 22.48 µg/g) in control to (29.40, 29.11 µg/g) for $T_3$: NPK+Zn (f). Grain Zn concentration increased by (47.34, 51.96 %) from (23.64, 22.48 µg/g) in control to (34.83, 34.48 µg/g) for treatment $T_4$: NPK+Zn (s)+Zn (f). Grain Zn concentration increased by (56.47, 62.81 %) from (23.64, 22.48 µg/g) of control to (36.99, 36.60 µg/g) for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Similar results were reported by Dhaliwal *et al* (2012), Hussain *et al* (2012) and Zou *et al* (2012).

Among the wheat varieties, the highest straw Zn concentration (31.98, 31.56 µg/g) was in variety PBW 550 followed by statistically inferior variety PBW 621 (30.52, 30.26 µg/g) followed by statistically inferior variety HD 2967 (28.32, 27.79 µg/g).

All the treatments of nutrient management were significantly higher than control (21.87, 21.44 µg/g). The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (37.66, 37.48 µg/g) which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f) (36.28, 36.13 µg/g) which was significantly higher than all other treatments. The significant effect of soil/foliar application of Zn on straw Zn concentration is apparently visible with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_4$: NPK+Zn (f) with NPK control. Straw Zn concentration increased by (25.29, 24.72 %) from (21.87, 21.44 µg/g) in control to (27.40, 26.74 µg/g) for $T_2$: NPK+Zn (s) by. Straw Zn concentration increased by (41.34, 42.40 %) from (21.87, 21.44 µg/g) in control to (30.91, 30.53 µg/g) for $T_3$: NPK+Zn (f). Straw Zn concentration increased by (65.89, 68.52 %) from (21.87, 21.44 µg/g) in control to (36.28, 36.13 µg/g) for treatment $T_4$: NPK+Zn (s)+Zn (f). Straw Zn concentration increased by (72.20, 74.81 %) from (21.87, 21.44 µg/g) to (37.66, 37.48 µg/g) under the treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). These results are in line with those of Dhaliwal *et al* (2012).

**4.4.1 Effect on Zn uptake in grain, straw and crop**

The perusal of data given in Annexure XIV, Table 15 shows that among wheat varieties, Zn uptake in grain and straw was statistically different in all the three varieties. Highest Zn uptake in grain was in variety PBW 550 (158.70, 147.91 g/ha) followed by HD 2967 (126.11, 121.13 g/ha) followed by PBW 621 (138.30, 143.61 g/ha).

In the treatments of nutrient management of grain Zn uptake, all the treatments were significantly higher than control (78.62, 68.12 g/ha). The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (206.83, 206.96 g/ha) which was significantly higher than all other treatments. The significant effect of soil/foliar application of Zn on Zn uptake in grain is evident with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_4$: NPK+ +Zn (s)+Zn (f) with NPK control. Zn uptake in grain increased by (54.86, 66.29 %) from (78.62, 68.12 g/ha) in control to (121.75, 113.28 g/ha) for $T_2$: NPK+Zn (s) by. Zn uptake in grain increased by (86.76, 102.91 %) from (78.62, 68.12 g/ha) in control to (146.83, 138.22 g/ha) for $T_3$: NPK+Zn (f). Zn uptake in grain increased by (129.74, 172.80 %) from (78.62, 68.12 g/ha) in control to (180.62, 185.83 g/ha) for treatment $T_4$: NPK+Zn (s)+Zn (f). Zn uptake in grain increased by (163.08, 200.21 %) from (78.62, 68.12 g/ha) of control to (206.83, 204.50 g/ha) for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Similar results were reported by Dhaliwal *et al* (2012).

Among wheat varieties, Zn uptake in straw was statistically superior in PBW 550 than HD 2967 during both the years. However, it was statistically at par with among PBW 621 and HD 2967 in the 1$^{st}$ year but different in the 2$^{nd}$ year among these varieties. Total Zn uptake in crop was highest in the variety PBW 621 (368.83, 349.78 g/ha) which was statistically at par with PBW 550 (359.68, 335.10 g/ha) but significantly higher than HD 2967 (335.18, 317.47 g/ha).

In the treatments of nutrient management of Zn uptake in straw, all the treatments were significantly higher than control (140.15, 118.50 g/ha). The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (296.33, 272.56 g/ha) which was significantly higher than all other treatments. The significant effect of soil/foliar application of Zn on Zn uptake in straw is clear with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_4$: NPK+ +Zn (s)+Zn (f) with NPK control. Zn uptake in straw increased by (32.49, 42.51 %) from (140.15, 118.50 g/ha) in control to (185.69, 168.87 g/ha) for $T_2$: NPK+Zn (s) by. Zn uptake in straw increased by (54.17, 69.99 %) from (140.15, 118.50 g/ha) in control to (216.07, 201.44 g/ha) for $T_3$: NPK+Zn (f). Zn uptake in straw increased by (81.10, 112.70 %) from (140.15, 118.50 g/ha) in control to (253.81, 252.05 g/ha) for treatment $T_4$: NPK+Zn (s)+Zn (f). Zn uptake in straw increased by (111.44, 130.01 %) from (140.15, 118.50 g/ha) of control to (296.33, 272.56 g/ha) for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Similar results were reported by Dhaliwal *et al* (2012).

Among wheat varieties, total Zn uptake was highest in the variety PBW 621 (368.83, 349.78 g/ha) which was statistically at par with PBW 550 (359.68, 335.10 g/ha) but significantly higher than HD 2967 (335.18, 317.47 g/ha).

In the treatments of nutrient management of total Zn uptake in crop, all the treatments were significantly higher than control (218.77, 186.60 g/ha). The best treatment was $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) (503.16, 477.06 g/ha) which was significantly higher than all other treatments. The significant effect of soil/foliar application of Zn on Zn uptake in crop is clear with comparison of $T_2$: NPK+Zn (s) and $T_3$: NPK+Zn (f) and $T_4$: NPK+ +Zn (s)+Zn (f) with NPK control. Zn uptake in crop increased by (40.53, 51.21 %) from (218.77, 186.60 g/ha) in control to (307.44, 282.15 g/ha) for $T_2$: NPK+Zn (s) by. Zn uptake in crop increased by (65.88, 82.03 %) from (218.77, 186.60 g/ha) in control to (362.90, 339.66 g/ha) for $T_3$: NPK+Zn (f). Zn uptake in crop increased by (98.58, 134.66 %) from (218.77, 186.60 g/ha) in control to (434.43, 437.88 g/ha) for treatment $T_4$: NPK+Zn (s)+Zn (f). Zn uptake in crop increased by (129.99, 155.66 %) from (218.77, 186.60 g/ha) of control to (503.16, 477.06 g/ha) for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Similar results were reported by Dhaliwal *et al* (2012).

**4.4.2 Effect on iron concentration in grain and straw**

The perusal of data given in Annexure XIV, Table 14 shows that among the wheat varieties the highest grain Fe concentration was in variety PBW 550 (38.04, 36.95 µg/g) which was significantly higher than both varieties PBW 621 (36.99, 36.28 µg/g) and HD 2967 (36.70, 35.88 µg/g).

All the treatments of nutrient management were significantly higher than control (31.31, 30.67 µg/g). The best treatment was $T_9$: NPK+$N_{50}$+Fe (f) (43.43, 43.04 µg/g), which was significantly higher than second best treatment $T_5$: NPK+Fe (f) (42.82, 41.23 µg/g). Grain Fe concentration increased by (36.76, 34.43 %) from (31.31, 30.67 µg/g) of control to

(42.82, 41.23 µg/g) in $T_5$: NPK+Fe (f). Grain Fe concentration increased by (38.71, 19.33 %) from (31.31, 30.67 µg/g) of control to (43.43, 43.04 µg/g) in $T_9$: NPK+$N_{50}$+Fe (f).

Out of three wheat varieties, the highest value of straw Fe concentration (222.2, 218.53 µg/g) was in variety PBW 550 followed by significantly inferior value in HD 2967 (213.92, 212.33 µg/g) followed by PBW 621 (208.50, 215.30 µg/g).

All the treatments of nutrient management were significantly higher than control (202.29, 197.58 µg/g). The best treatment was $T_9$: NPK+$N_{50}$+Fe (f) (236.29, 233.10 µg/g) which was significantly higher than next best treatment $T_5$: NPK+Fe (f) (231.29, 229.28 µg/g). Fe concentration in straw increased by (14.34, 16.04 %) from (202.29, 197.58 µg/g) of control to (231.29, 229.28 µg/g) in $T_5$: NPK+Fe (f). Fe concentration in straw increased by (16.81, 17.98 %) from (202.29, 197.58 µg/g) of control to (236.29, 233.10 µg/g) in $T_9$: NPK+$N_{50}$+Fe (f). These findings are in accordance with Dhaliwal *et al* (2009).

**4.4.3 Effect on Fe uptake in grain, straw and crop**

The data given in Annexure IV, Table 15 signifies that among wheat varieties, maximum Fe uptake in grain was in variety PBW 550 (195.39, 179.38 g/ha) followed by statistically inferior to PBW 621 (176.02, 178.45 g/ha). The variety PBW 621 was statistically at par with HD 2967 (168.01 g/ha) in the 1st year, however PBW 621 (178.45 g/ha) was significantly superior to HD 2967 (160.35 g/ha) in Fe uptake in grain.

All the treatments of nutrient management of grain Fe uptake were significantly higher than control (113.31, 101.52 g/ha). The treatment $T_9$: NPK+$N_{50}$+Fe (f) (203.67, 193.12 g/ha) was was significantly higher than treatment $T_5$: NPK+Fe (f) (187.60, 171.85 g/ha) but statistically at par with treatments $T_4$: NPK+ +Zn (s)+Zn (f) and $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) Fe uptake in grain increased by (65.72, 69.28 %) from (113.31, 101.52 g/ha) of control to (187.60, 171.85 g/ha) in $T_5$: NPK+Fe (f). Fe uptake in grain increased by (79.90, 90.23 %) from (113.31, 101.52 g/ha) of control to (203.67, 193.12 g/ha) in $T_9$: NPK+$N_{50}$+Fe (f). These findings are in accordance with Dhaliwal *et al* (2009). Similar results were given by Ziaeian and Malakouti (2001) who reported that Fe application at critical growth stages of wheat increased concentration and total uptake of Fe in wheat grains.

Among wheat varieties, Fe uptake in straw was maximum in variety PBW 621(1626.32, 1448.45 g/ha) which was significantly superior to both varieties HD 2967 (1566.67, 1479.82 g/ha) and PBW 550 (1408.13, 1285.45) in the 1st year of study. Fe uptake in straw was maximum in variety HD 2967 which was significantly superior to both varieties PBW 621 and PBW 550 in the 2nd year of study.

All the treatments of nutrient management of Fe uptake in straw were significantly higher than control (1302.42, 1094.20 g/ha). The treatment $T_9$: NPK+$N_{50}$+Fe (f) (1666.38, 1480.26 g/ha) was significantly higher than treatment $T_5$: NPK+Fe (f) (1579.03, 1364.48

g/ha) but statistically at par with treatments $T_4$: NPK+ +Zn (s)+Zn (f) and $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Fe uptake in straw increased by (21.24, 24.70 %) from (1302.42, 1094.20 g/ha) of control to (1579.03, 1364.48 g/ha) in $T_5$: NPK+Fe (f). Fe uptake in straw increased by (27.94, 35.28 %) from (1302.42, 1094.20 g/ha) of control to (1666.38, 1480.26 g/ha) in $T_9$: NPK+$N_{50}$+Fe (f). These findings are in accordance with Dhaliwal *et al* (2009) and Ziaeian and Malakouti (2001) who reported that Fe application at critical growth stages of wheat increased concentration and total uptake of Fe in wheat straw.

Among wheat varieties, both varieties PBW 621 (1802.34, 1626.90 g/ha) and HD 2967 (1734.68, 1640.17 g/ha) were significantly superior to variety PBW 550 (1603.52, 1464.83 g/ha) but statistically at par with each other.

All the treatments of nutrient management of Fe uptake in crop were significantly higher than control (1415.63, 1195.72 g/ha) except $T_2$ : NPK+Zn (s) (1586.15 g/ha) in the 1st year of study. The treatment $T_9$: NPK+$N_{50}$+Fe (f) (1870.05, 1673.38 g/ha) was was significantly higher than treatment $T_5$: NPK+Fe (f) (g/ha) but statistically at par with treatments $T_4$: NPK+ +Zn (s)+Zn (f) and $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Fe uptake in crop increased by (24.79, 28.49 %) from (1415.63, 1195.72 g/ha) of control to (1766.63, 1536.33 g/ha) in $T_5$: NPK+Fe (f). Fe uptake in crop increased by (32.10, 40.78 %) from (1415.63, 1195.72 g/ha) of control to (1870.05, 1673.38 g/ha) in $T_9$: NPK+$N_{50}$+Fe (f). These findings are in accordance with Dhaliwal *et al* (2009) and Ziaeian and Malakouti (2001).

**4.5 Conclusions**

Among varieties, PBW 550 recorded the highest effective tillers/$m^2$, ear length, no of grains/ear, grain yield, maximum content of N and concentration of Zn and Fe in grain and straw, which were significantly better than varieties PBW 621 and HD 2967 during both years of study. Significant qualitative improvement in grain appearance score, hectolitre weight and grain hardness and SDS-Sedimentation value and protein content was observed in variety PBW 550 in comparison to PBW 621 and HD 2967 during both years of study. All the three varieties were non-significant in Phenol reaction score in both years of study.

In the present study, grain yield has increased by (54.67, 70.94 %) from control values (36.11, 33.07 q/ha) to (55.85, 56.53 q/ha) of best treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f).The straw yield increased by (22.51, 31.62 %) from control values (64.46, 55.41q/ha) to the highest value of best treatment $T_8$: NPK+Zn (s)+ $N_{50}$+Zn (f) (78.97, 72.93 q/ha). The harvest index (HI) also increased from (35.90, 37.38) of control to (41.43, 43.66) in $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Grain Zn concentration increased by (56.47, 62.81 %) from (23.64, 22.48 µg/g) of control to (36.99, 36.60 µg/g) for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Grain Fe concentration increased by (38.71, 19.33 %) from (31.31, 30.67 µg/g) of control to (43.43, 43.04 µg/g) in $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). The combined effect of soil and foliar application

of zinc sulphate and increased level of N due to its application as top-dressing before heading in treatment $T_8$ increased assimilation to grain sink. Hence, Zn and Fe foliar sprays increased yield of straw, grain and enhanced Zn and Fe concentrations in grain significantly over control.

It can be concluded from the experiment 1 that application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 DAS in combination with soil application of zinc sulphate @62.5 kg/ha and three foliar sprays of 0.5 % $ZnSO_4$. $7H_2O$ and 0.5 % $FeSO_4$. $7H_2O$ are beneficial in improving growth, yield, uptake of nitrogen agronomic biofortification of zinc and iron and grain quality.

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**Experiment 2: Impact of nitrogen, manganese and copper on growth, productivity, agronomic biofortification and quality of wheat.**

**4.6 Growth characters**

**4.6.1 Emergence count**

The data given in Annexure XIV, Table 16 showed that various varieties, nutrient treatments and their interactions did not show any significant difference. It indicated that plant population was uniform in all the plots.

**4.6.2 Plant height (cm)**

The data given in Annexure XIV, Table 17 showed that at harvest, the plant height of wheat varieties PBW 621 (87.6, 83.5 cm) and HD 2967 (88.7, 84.2 cm) were statistically at par in height but significantly higher than PBW 550 (76.4, 74.3 cm). All nutrient treatments had significantly more height than control. The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (89.6, 86.6 cm), which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (88.5, 84.4 cm). Further, $T_4$ was statistically at par with $T_5$: NPK+$N_{50}$+Mn (f) having values (86.2, 84.4 cm) but significantly higher than $T_2$: NPK+Mn (f) (83.1, 80.4 cm) and $T_3$: NPK+Cu (f) (80.1, 75.6 cm).

The increase in plant height might be attributed to the role of N, Mn and Cu in plant growth, metabolism and higher photo-synthetic activity. Cells developed with elevated level of N tend to be large and having higher meristematic activity and formation of protoplasm which increases the plant growth (Havlin *et al* 2010).

**4.6.3 Dry matter accumulation (q/ha)**

Dry biomass given in Annexure XIV, Table 17 showed that wheat varieties showed significant effect on dry matter accumulation.The variety PBW 550 (108.1, 108.8 q/ha) produced significantly lower dry matter than PBW 621 (114.3, 116.3 q/ha). The variety PBW 621 was statistically at par with variety HD 2967 (110.2, 111.7 q/ha). The differences in dry matter accumulation are due to differential increase in vegetative growth rate of these varieties.

In the treatments of nutrient management, $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (133.1, 130.6 q/ha) recorded the highest dry matter yield, which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) (126.8, 124.3 q/ha), which was significantly higher than all other treatments. All nutrient treatments were significantly superior to control in height. It was reported earlier also that soil and foliar applied Mn significantly increased crop-biomass apart from role of N in boosting plant growth (Narwal *et al* 2010 and Dhaliwal *et al* 2011).

**4.6.4 Leaf area index (LAI)**

Annexure XIV, Table 19 shows that among the varieties, LAI differed significantly. The variety PBW 550 (3.56, 3.52) recorded significantly lower LAI than PBW 621 (3.88, 3.83).

The variety PBW 621 was significantly higher than HD 2967 (3.75, 3.69) during both the years of study. This might be due to differential ability of wheat varieties in LAI and tillering habit. Moreover, PBW 550 is shy in tillering. Similar results were reported by Hussain *et al* (2012).

During both years, nutrient management treatments had significant effect on LAI. Treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (4.35, 4.27) recorded significantly higher LAI than all the treatments. The second best treatment was $T_4$ [NPK+Mn (f)+Cu (f)] (3.85, 3.82), which was significantly higher than treatments $T_1$: NPK (Control) (3.12, 2.90), $T_2$: NPK+Mn (f) (3.28, 3.24), $T_3$: NPK+Cu (f) (3.25, 3.21), $T_5$: NPK+$N_{50}$+Mn (f) (3.58, 3.54) and $T_6$: NPK+$N_{50}$+Cu (f) (3.40, 3.36). All treatments were significantly higher than control.

It might be attributed to reason that vegetative growth resulting from higher photosynthetic activities might be affected by additional dose of N @50 kg/ha just before heading combined with foliar application of Mn/Cu and its synergistic effect with foliar application of Mn and Cu. It was reported earlier also that increase in N dose before anthesis can result in LAI by 62 % (Salvagiotti and Miralles 2008).

**4.6.5 Periodic tiller count**

The perusal of the data in Annexure XIV, Table 20 shows that the variety PBW 621 (345, 340 tillers/$m^2$) was statistically at par with HD 2967 (340, 338 tillers/$m^2$) but significantly higher than PBW 550 (323, 320 tillers/$m^2$) at 90 DAS. At 120 DAS, both varieties PBW 621(327, 323 tillers/$m^2$) and HD 2967 (323, 320 tillers/$m^2$) were statistically at par with each other but significantly higher than PBW 550 (307, 305 tillers/$m^2$)

The maximum tillers were produced at 90 DAS with the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (394, 390 tillers/$m^2$) which were significantly higher than all other treatments such as $T_1$: NPK (Control) (325, 320 tillers/$m^2$), $T_2$: NPK+Mn(f) (345, 340 tillers/$m^2$), $T_3$: NPK+Cu (f) (337, 332 tillers/$m^2$), $T_4$ [NPK+Mn(f)+Cu(f)] (385, 380 tillers/$m^2$), $T_5$: NPK+$N_{50}$+Mn(f) (375, 371 tillers/$m^2$) and $T_6$: NPK+$N_{50}$+Cu (f) (367, 362 tillers/$m^2$). This may be attributed to the synergistic effect of Mn/Cu and N on tillering. Improved supply of nutrients induced higher tillering as compared to lower N status. It was also reported that N application had tremendous effect on formation and survival of tillers (Rehman *et al* 2002). Tiller count for all the treatments including maximum tiller number for $T_7$ (375, 371 tillers/$m^{2)}$ decreased 120 DAS in comparison to tiller count at 90 DAS.

The increase in tiller number with the increase in micronutrient and nitrogen availability is attributed to the rapid conversion of carbohydrates in to proteins and consequently increased the number and size of growing cells which ultimately resulted in increase in number of tillers (Singh and Aggarwal 2001).

## 4.7 YIELD ATTRIBUTES

### 4.7.1 Effective tillers at harvest

Annexure XIV, Table 21 indicated that the variety PBW 621 (319, 312 tillers/$m^2$) produced the highest number of effective tillers, which was significantly higher than PBW 550 (300, 295 tillers/$m^2$) but statistically at par with HD 2967 (315, 310 tillers/$m^2$) during both years of study.

All the treatments of nutrient management were significantly higher than control. The maximum number of effective tillers were produced with the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (364, 355 tillers/$m^2$) which were significantly higher than all other treatments such as $T_1$: NPK (Control) (284, 275 tillers/$m^2$), $T_2$: NPK+Mn(f) (315, 312 tillers/$m^2$), $T_3$: NPK+Cu(f) (308, 305 tillers/$m^2$), $T_4$ [NPK+Mn(f)+Cu(f)] (355, 349 tillers/$m^2$), $T_5$: NPK+$N_{50}$+Mn(f) (345, 340 tillers/$m^2$) and $T_6$: NPK+$N_{50}$+Cu (f) (337, 335 tillers/$m^2$). The increased effective tillers/$m^2$ with higher dose of N on tillering through cytokinin-synthesis resulting into more number of effective tillers/$m^2$ (Gardner *et al* 1988, Sinha and Rai 1991). it has been reported earlier that semi-dwarf varieties due to exploitation of more assimilates to the ear during pre-flowering period result in higher number of fertile tillers/$m^2$ and more fertile florets (Calderini *et al* 1995,Miralles *et al* 1998). Mn being part of photosynthetic machinery also contributed to enhanced photo-synthesis (Marschner and Cakmak 1996).

### 4.7.2 Ear length (cm)

The data presented in Annexure XIV, Table 21 shows that the variety PBW 550 (10.4, 10.5 cm) produced the highest ear length which was significantly higher than PBW 621 (9.9, 9.3 cm) and HD 2967 (9.1, 8.8 cm). PBW 621 and HD 2967 were statistically at par with each other for ear length.

All the treatments of nutrient management were significantly higher than control (8.7, 8.4 cm). The treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best one (10.7, 10.4 cm) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (10.4, 10.3 cm). The treatment $T_4$ was significantly higher than all other treatments such as $T_2$: NPK+Mn (f) (9.1, 9.7cm), $T_3$: NPK+Cu (f) (9.2, 9.1 cm), $T_5$: NPK+$N_{50}$+Mn (f) (10.1, 9.8 cm) and $T_6$: NPK+$N_{50}$+Cu (f) (9.6, 9. cm). These results are in accordance with findings of Rao and Bhardwaj (1981) who reported that increase in ear-head length has been reported earlier up to 160 kg N/ha.

### 4.7.3 Number of grains/ear

The data of number of grains/ear are presented in Annexure XIV, Table 21. Among the varieties, PBW 550 (46.7, 44.6) produced the highest number of grains/ear which was significantly higher than varieties PBW 621 (42.9, 41.2) and HD 2967 (37.7, 36.3). The varieties PBW 621 and HD 2967 were statistically at par with each other for number of grains/ear.

All the treatments of nutrient management were significantly higher than control (41.0, 39.3). The best treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (44.6, 42.3) was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (43.7, 42.0). Further, the treatment $T_4$ was significantly higher than all other treatments such as $T_2$: NPK+Mn (f) (41.9, 40.4), $T_3$: NPK+Cu (f) (41.2, 39.9), $T_5$: NPK+$N_{50}$+Mn (f) (42.9, 41.5) and $T_6$: NPK+$N_{50}$+Cu (f) (41.8, 39.9). Adequate availability of N might have increased the grains/ear by preventing the degradation of spikelets at the time of grain development. The increased number of spikelets led to incremental increases in spike length. Similar results were reported earlier also (Reddy and Bhardwaj 1989).

All Interaction effects were significant (Table 22). The interaction values indicated that the highest values of number of grains/ear were reported for the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (49.5, 47.2) for variety PBW 550. The variety PBW 550 was significantly superior to PBW 621 (44.1, 42.7). The variety PBW 621 was significantly superior to HD 2967 (39.4, 37.1). $T_7$ was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) for varieties HD 2967 and PBW 621 but differed significantly under variety PBW 550. The lowest number of grains/ear were reported for the control plots having variety HD 2967 (35.9, 34.7), which was statistically inferior to control plots having variety PBW 621 values (40.1, 41.0). The control plots sown with variety PBW 550 (45.3, 43.1) were statistically superior to control plots sown with variety PBW 621 (45.3, 43.1).

**4.7.4 Thousand grain weight (g)**

The data is presented in Annexure XIV, Table 21. The variety PBW 550 (43.5, 42.6 g) produced the highest thousand grain weight, which was significantly higher than variety PBW 621 (40.6, 39.6 g) and HD 2967 (40.5, 38.7 g).

All the treatments of nutrient management were significantly higher than control (37.8, 35.6 g). The best treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (45.0, 44.7 g) was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (43.9, 43.7 g). Further, $T_4$ was significantly higher than all other treatments except $T_5$: NPK+$N_{50}$+Mn (f) (42.8, 41.1 g). This may be attributed to the synergistic effect of N and foliar application of Mn/Cu which might have incrased the thousand grain weight.

**4.7.5 Grain yield (q/ha)**

The data on grain yield is presented in Annexure XIV, Table 23. All the three varieties were statistically at par with each other for grain yield.

All the treatments of nutrient management were significantly higher than control (29.25, 32.51 q/ha). $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment (54.15, 53.71 q/ha), which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) (52.65, 51.73 q/ha). The treatment $T_4$ was statistically at par with the treatment $T_5$: NPK+$N_{50}$+Mn (f) (48.70, 47.43

q/ha). Further, $T_5$ was significantly higher than other treatments such as $T_2$: NPK+Mn (f) (47.57, 44.93 q/ha), $T_3$: NPK+Cu (f) (42.53, 43.54 q/ha) and $T_6$: NPK+$N_{50}$+Cu (f) (45.14, 45.20 q/ha). The significant effect of foliar application of Mn and Cu is apparently visible with comparison of $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f) with NPK control. Grain yield increased by (62.63, 38.20 %) from (29.25, 32.51 q/ha) in control to (47.57, 44.93 q/ha) for $T_2$: NPK + Mn (f). Grain yield increased by (45.40, 33.93 %) from (29.25, 32.51 q/ha) in control to (42.53, 43.54 q/ha) for $T_3$: NPK+Cu (f). Grain yield has increased by (85.10, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) for best treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f).

Mn promoted evolution of oxygen in photosynthesis, enzyme activation in electron transport and disease-resistance (Marschner *et al* 1996) thereby enhancing phtosynthates, their increased translocation to grain and finally increased yield in the treatments $T_2$: NPK + Mn (f), $T_4$: NPK+Mn (f)+Cu (f), $T_5$: NPK+$N_{50}$+ Mn(f) and $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). Copper involved in various cell and plant growth functions as a constituent of cytochrome oxidase and component of many enzymes and promoted synthesis of vitamin A (Marschner *et al* 1996) resulting in increased photosynthesis and photosynthates and their translocation into grain thereby increasing crop yield in the treatments $T_3$: NPK+Cu (f), $T_4$: NPK+Mn (f)+Cu (f), $T_6$: NPK+$N_{50}$+Cu (f) and $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f).

The increase in grain yield was due to the cumulative effect of increase in all the yield-attributing components such as effective tillers/$m^2$, number of grains/ear, spike length and thousand grain weight (Annexure XIV, Table 23). Additional N supply before heading and foliar application of Mn and Cu might have increased grain yield through more allocation of dry matter to grains. Similar results were reported earlier also (Asad *et al* 2000, Dhaliwal *et al* 2011, Kataki *et al* 2001 and Madani *et al* 2010). All the interaction effects were non significant irrespective of varieties and treatments of nutrient mangaement (Annexure XIV, Table 24).

**4.7.6 Straw yield (q/ha)**

The straw yield is presented in Annexure XIV, Table 23. All the three varieties were statistically at par with each other for straw yield.

All the treatments of nutrient management, were significantly higher than control (45.22, 52.79 q/ha). $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment (76.59, 75.81 q/ha), which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (72.13, 76.45 q/ha). The treatment $T_4$: NPK+Mn (f)+Cu (f) was significantly superior to $T_3$: NPK+Cu (f) (58.56, 67.17 q/ha) by (23.17, 13.82 %) and $T_6$: NPK+$N_{50}$+Cu (f) (60.89, 67.04 q/ha) by (25.78, 14.04 %). The significant effect of foliar application of Mn and Cu is apparently visible with comparison of $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f) with NPK control. Straw yield increased by (14.05,

3.10 %) from (58.56, 67.17 q/ha) in control to (66.79, 69.22 q/ha) for $T_2$: NPK + Mn (f). Straw yield increased by (29.50, 27.24 %) from (45.22, 52.79 q/ha) in control to (58.56, 67.17 q/ha) for $T_3$: NPK+Cu (f). Straw yield has increased by (68.37, 43.61 %) from (45.22, 52.79 q/ha) in control to (76.59, 75.81 q/ha) for best treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f).

The increase in straw yield was due to the cumulative effect of increase in all the straw yield attributing indices such as plant height, dry matter accumulation, LAI and number of tillers (Annexure XIV, Table 23). The increase in straw yield may be due to the combined effect of Cu and Mn increased wheat dry matter, straw yield and grain yield significantly over control. Similar results were given earlier by others (Arif *et al* 2006).

**4.7.7 Harvest index (HI)**

The data given in Annexure XIV, Table 23 showed that wheat varieties had significant effect on HI. The variety PBW 550 (43.05, 42.84) had significantly higher HI in comparison to varieties HD 2967 (42.02, 39.14) and PBW 621 (39.72, 38.63). The variety PBW 621 recorded lowest harvest index. Similar results were reported by Mughal *et al* (2011).

All the treatments of nutrient management were significantly higher as compared to control (39.28, 38.11) during both the years.The treatment $T_5$: NPK + $N_{50}$ + Mn (f) (42.25, 39.85) was statistically at par in HI with $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (41.42, 41.46). This might be due to favourable effects of increased availability of nitrogen, Mn and Cu on growth and yield attributing characters which helped in the translocation of photosynthates to grain and increased the grain yield (Arif *et al* 2006).

**4.8 Quality Parameters**

**4.8.1 Physical grain characteristics**

**4.8.1.1 Grain appearance score**

The data in Annexure XIV, Table 25 shows that the variety PBW 550 scored the highest grain appearance score (5.7, 5.8) during both the years and were significantly higher than PBW 621 (5.3, 5.5). PBW 621 was statistically at par with HD 2967 (5.1, 5.4). For the nutrient management treatments, the highest values of grain appearance score were reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f) + Cu (f) (5.8, 6.0), which was significantly higher than $T_5$: NPK+$N_{50}$+Mn (f) (5.5, 5.7) and $T_6$: NPK+$N_{50}$+Cu (f) (5.4, 5.6). The treatment $T_6$ was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (5.4, 5.5). All the treatments $T_2$: NPK+Mn (f) (5.2, 5.4), $T_4$: NPK+Mn+Cu (f) (5.4, 5.5) (f), $T_5$: NPK+$N_{50}$+Mn(f) (5.5, 5.7) and $T_6$: NPK+$N_{50}$+Cu (f) (5.4, 5.6) were significantly higher than control (5.0, 5.1) except $T_3$: NPK+Cu (f) (5.2, 5.3).

The interaction effects were significant in both the years as given in Annexure XIV, Table 27. The interaction values indicated that the highest grain appearance score was

reported under treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) under variety PBW 550 (6.0, 6.2), which was significantly higher than $T_7$ under variety PBW 621 (5.7, 6.1) which was statistically higher than $T_7$ under variety HD 2967 (5.4, 5.8). The highest grain appearance score for the control plots were reported under variety PBW 550 (5.3, 5.3), which was statistically superior to control plots under variety PBW 621 (5.0, 5.1). Control plots having variety PBW 621 (5.0, 5.1) were statistically superior to control plots under variety HD 2967 (4.7, 4.9) for grain appearance score.

**4.8.1.2 Hectolitre weight (kg/hl)**

The data in Annexure XIV, Table 25 shows that the hectolitre weight was higher during the year 2011-12 than 2012-13 reflecting the better growing conditions during the grain ripening period. The variety PBW 550 recorded the highest hectolitre weight (79.5, 79.4 kg/hl) which was significantly higher than PBW 621 (75.7, 75.4 kg/hl), that was statistically at par with HD 2967 (75.1, 74.9 kg/hl). Under the nutrient treatments the highest values of hectolitre weight (77.9, 77.8 kg/hl) was reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was statistically at par with the treatment $T_4$: NPK+Cu (f)+Mn (f) having values (77.7, 77.4 kg/hl) and $T_5$: NPK+$N_{50}$+Mn (f) (76.9, 76.9 kg/hl) and $T_2$: NPK+Mn (f) (77.2, 76.8 kg/hl). All of these treatments were significantly higher than control. Hectolitre weight increased with the elevated nitrogen level due to increase in grain density. Similar results were reported earlier (kaur *et al* 2006).

**4.8.1.3 Grain hardness (kg)**

The data in Annexure XIV, Table 25 shows that the grain hardness values were comparatively higher during the year 2012-13 than 2011-12 reflecting the harsh growing conditions during the grain ripening period. The variety PBW 550 recorded the highest grain hardness (11.9, 12.1 kg) which were significantly higher than PBW 621 (10.8, 11.0 kg). The grain hardness for variety PBW 621 was significantly higher than variety HD 2967 (9.2, 9.7 kg) during both the years. Under the nutrient treatments, the highest values of grain hardness (11.8, 12.1 kg) were reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than the treatment $T_5$: NPK+$N_{50}$+Mn (f) (11.1, 11.5 kg). The treatment $T_5$ was statistically at par with the treatment $T_6$: NPK+$N_{50}$+Cu (f) (10.8, 11.2 kg) and $T_6$ was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (10.7, 10.8 kg). All the nutrient management treatments proved significantly higher than control. It was reported earlier also that the grain hardness increased with increase in nitrogen level (kaur *et al* 2006).

**4.8.2 Chemical grain characteristics**

**4.8.2.1 Protein content (%)**

The data in Annexure XIV, Table 26 shows that the protein content values were non-significant in all the three varieties for both the years however, the highest values of two years

for protein content were reported in variety PBW 550 (12.33, 12.62 %) followed by PBW 621 (12.24, 12.31 %) followed by HD 2967 (12.05, 12.15 %). Under nutrient management treatments, the highest values of Protein content (13.21, 13.17 %) were reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than the treatment $T_5$: NPK+$N_{50}$+Mn (f) (12.57, 12.74 %) which was statistically at par with both the treatments like $T_6$: NPK+$N_{50}$+Cu (f) (12.52, 12.65 %) and $T_4$: NPK+Mn (f)+Cu (f) having values (12.19, 12.31 %). All the nutrient management treatments viz. $T_2$: NPK+Mn (f) (11.95, 12.19 %) and $T_4$: NPK+Mn (f)+Cu (f) (12.19, 12.31 %), $T_5$: NPK+$N_{50}$+Mn (f) (12.57, 12.74 %), $T_6$: NPK+$N_{50}$+Cu (f) (12.52, 12.65 %) and $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (13.21, 13.17 %) were significantly higher than control (11.33, 11.50 %) during both the years except $T_3$: NPK+Cu (f) (11.69, 11.97 %) which was statistically at par with control.

The significant effect of foliar application of Mn alone and combined application of N with foliar application of Mn and Cu is crystal clear in comparison to$T_2$: NPK+Mn (f) with NPK control. Protein content significantly increased from control value of (11.33, 11.50 %) to (11.95, 12.19 %) for $T_2$: NPK + Mn (f). Protein content significantly increased from (11.33, 11.50 %) in control to (13.21, 13.17 %) for $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f).

All the nutrient management treatments proved significantly higher than control during both the years except NPK + Cu (f) which was statistically at par with control. The foliar application of Mn and Cu along with increased dose of nitrogen improved the protein content significantly.

These results have been supported earlier also (Fischer 1993, Ortiz-Monsterio *et al* 1994, Shi *et al* 2010 and Zeidan *et al* 2010). In the treatments of nutrient management, foliar application of micronutrients significantly increased protein contents in wheat grains as compared to control, which contributed to increase in grain hardness and sedimentation values (Anexure XI.). Manganese and copper also played an important role in plant processes, including the metabolism of nitrogen. Improved nitrogen metabolism increased the amount of nitrogen that was incorporated into the developing proteins.

**4.8.2.2 SDS-Sedimentation value (cc)**

The data in Annexure XIV, Table 26 showed that among varieties, the highest values of both years for sedimentation values were reported in variety PBW 550 (53, 55 cc), which was significantly superior to PBW 621 (48, 50 cc). PBW 621 and HD 2967 were at par with each other.

During both years, under nutrient management treatments, the highest values of sedimentation values (53, 55 cc) were reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than $T_5$: NPK+$N_{50}$+Mn (f) (51, 53 cc) which was

significantly higher than $T_6$: NPK+$N_{50}$+Cu (f) (49, 52 cc) which was statistically at par with the treatment $T_4$: NPK+Mn (f)+Cu (f) reporting values (48, 51 cc).

In the year 2012-13, all nutrient treatments were significantly higher than control. These results are in line of protein content. Actually, gluten up to 90 % is constituted by the proteins and the improvement in proteins caused the higher development of significantly higher gluten and consequently in the improvement in sedimentation value (Fig 2.). Similar trend was reported earlier (Mehta *et al* 2006).

The interaction effects were significant in both the years which are reflected in Table 28. The interaction values of sedimentation value indicated that the highest values were reported for the treatment $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f) under variety PBW 550 (58, 60 cc), which was significantly superior to $T_7$ under HD 2967 (50, 51cc) and PBW 621 (51, 53 cc). $T_7$ under varieties HD 2967 and PBW 621 was statistically at par with each other. The lowest values of sedimentation value were reported in the plots receiving control treatment having variety HD 2967 (39, 41 cc) which was statistically inferior to control plots having variety PBW 621 (45, 47 cc), which was statistically inferior to control plots having variety PBW 550 (49, 51 cc).

**4.8.2.3 β-Carotene (ppm)**

The data in Annexure XIV, Table 26 showed that during the year 2011-12 and 2012-13, the highest value of β-carotene was recorded in HD 2967 (5.37, 5.69 ppm) which was significantly higher than PBW 550 (4.82, 5.17 ppm). The variety was statistically PBW 550 was at par with PBW 621 (4.80, 4.93 ppm). All treatments of nutrient management were significantly higher than control during both the years. The highest values of β-carotene (5.68, 5.98 ppm) were reported under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than the treatment $T_5$: NPK+$N_{50}$+Mn (f) (5.44, 5.63 ppm). Further, $T_5$ was statistically at par with $T_6$: NPK+$N_{50}$+Cu (f) (5.37, 5.59 ppm) and in turn $T_6$ was at par with $T_4$: NPK+Mn (f)+Cu (f) (5.21, 5.51 ppm). The interaction effects were non-significant in both the years.

**4.8.2.4 Phenol Reaction Score**

The data in Annexure XIV, Table 26 shows that the phenol reaction score is indicative of the Tyrosinase enzyme activity causing darkening of dough during storage and processing was comparatively higher during 2011-12 than 2012-13 due to the milder environment leading to escape of the enzyme. The lower phenol reaction score value is higher as such dough can be stored for long and the risk of darkening and nutritional losses is minimum. Phenol Reaction Score (phenol reaction score) was found non-significant in all the three varieties, nutrient treatments and their interaction in both years (Annexure XIV Table 26).

**4.9 Effect on grain nitrogen content**

The data in Annexure XIV, Table 29 shows that nitrogen content in grain was significantly higher in the variety PBW 550 (1.86, 1.80 %) which was significantly higher than PBW 621 (1.77, 1.82 %). Wheat variety PBW 621 was significantly higher than HD 2967 (1.72, 1.76 %) during both years of study.

Grain N content was significantly superior in all the nutrient management treatments than control (1.73, 1.78 %). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f) (1.85, 1.89 %) which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) (1.82, 1.87 %). Grain N content increased by (6.94, 6.18 %) from (1.73, 1.78 %) in control to (1.85, 1.89 %) in $T_7$: NPK+N50+Mn (f) +Cu (f) for both years of study. This may be due to the reason that due to the increased availability of N in the soil enhanced the uptake and N content in straw.

**4.10 Effect on straw nitrogen content**

The data in Annexure XIV, Table 29 shows that straw N content among varieties differed significantly. Straw N content was significantly higher in the variety PBW 550 (0.56, 0.58 %) which was significantly higher than HD 2967 (0.45, 0.48 %) which was statistically at par with PBW 621 (0.51, 0.54 %) during both years of study.

Straw N content was significantly superior in all the nutrient management treatments than control (0.44, 0.48 %) The best treatment was $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f) (0.58, 0.61 %) which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) (0.55, 0.58 %). Straw N content increased by (31.82, 27.08 %) from (0.44, 0.48 %) in control to (0.58, 0.61 %) in $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) for both years of study. This may be due to the reason that due to the increased availability of N in the soil enhanced the uptake and N content in straw.

**4.11 Effect on grain N uptake**

The data on nitrogen uptake by grain and straw and total N uptake in crop have been presented in Annexure XIV, Table 29. Grain N uptake differed significantly among varieties for both years of study. Grain N uptake by the variety PBW 550 grain (86.40, 88.13 kg/ha) was significantly higher than all other varieties, which was statistically at par among varieties HD 2967 (79.14, 79.02 kg/ha) and PBW 621 (79.10, 82.48 kg/ha).

The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (100.10, 100.50 kg/ha), which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (95.83, 96.74 kg/ha). The treatment $T_4$ was statistically at par with $T_5$: NPK+$N_{50}$+Mn (f) (87.17, 89.82 kg/ha) and $T_2$: NPK+Mn (f) (84.20, 81.32 kg/ha). $T_2$ was statistically at par with $T_6$: NPK+$N_{50}$+Cu (f) (79.45, 81.25 kg/ha). Grain N uptake increased by (97.79, 42.63 %) from control values (50.61, 57.87 kg/ha) to (100.10, 100.50 kg/ha) under $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f). Similar effects of nitrogen levels on nitrogen uptake were also observed by researchers (Kumar and Ahlawat 2006) in which nitrogen uptake increased with elevated nitrogen levels.

**4.12 Effect on straw N uptake**

All the three varieties were significantly different from each other for straw N uptake. The highest value of straw N uptake was recorded by recorded by wheat variety PBW 550 (34.18, 36.70 kg/ha) which was statistically at par with PBW 621 (34.35, 38.90 kg/ha), but both of these varieties were significantly higher than HD 2967 (28.38, 33.52 kg/ha) during both years of study (Annexure XIV, Table 29).

All the treatments of nutrient management were significantly higher than control (19.90, 25.34 kg/ha). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (44.42, 46.24 kg/ha) which was significantly higher than all other treatments. Straw N uptake increased by (123.22, 82.48 %). This may be due to the reason that due to the increased availability of N in the soil enhanced the uptake and N content in straw.

**4.13 Effect on total N uptake by crop**

Total N uptake differed significantly among varieties for both years of study. Total N uptake by the variety PBW 550 (120.58, 124.83 kg/ha) was significantly higher than PBW 621 and H D 2967 (Annexure XIV, Table 29).

The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (144.60, 147.76 kg/ha) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (135.50, 141.08 kg/ha), which was significantly higher than all other treatments. Total N uptake increased by (105.08, 77.57 %) from control values (70.51, 83.21 kg/ha) to (144.60, 147.76 kg/ha) under $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). This may be attributed to the reason that due to the increased availability of N in the soil by application of N as top dressing enhanced the uptake and N content in crop. The delayed application of N resulted in continuous supply in N for the longer period of time. Similar effects of increased nitrogen levels on nitrogen uptake were also observed earlier by Kumar and Ahlawat (2006).

**4.14 Interaction effect on N content in straw**

The data in Annexure XIV, Table 30 shows that Interaction effect of wheat varieties and nitrogen levels on nitrogen content and uptake in grain and total N uptake by crop was found to be non-significant. However, the interaction effect of N content in straw and its uptake was found to be significant as presented in Annexure XI.

The interaction values indicated that the highest values of N content in straw ( %) were reported in the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) and variety PBW 550 (0.64, 0.66 %), which were significantly higher than all other treatments. The 2$^{nd}$ highest values were reported for $T_7$ under variety PBW 621 (0.59, 0.63 %) which was significantly superior to HD 2967 (0.51, 0.53 %). For all the three varieties the best treatment was $T_7$. The lowest values of N content in straw were recorded in combination of treatment $T_1$: NPK control and variety HD 2967 (0.41, 0.44 %) which was statistically inferior to combination of control treatment

withvariety PBW 621 (0.44, 0.48 %) which was statistically inferior to combination of control treatment with variety PBW 550 (0.47, 0.51 %).

**4.15 Interaction effect on N uptake in straw**

The interaction values in The data in Annexure XIV, Table 31 shows that indicated that the highest values of straw N uptake were reported for the combination of $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (51.47, 54.50 kg/ha) for variety PBW 550 which proved significantly better than PBW 621 (48.59, 52.94 kg/ha) which was statistically better than HD 2967 (37.35, 42.70 kg/ha) for $T_7$. The lowest values of straw N uptake were reported in combination of control treatment with variety HD 2967 (16.10, 20.99 kg/ha) which was significantly inferior to combination of control treatment with variety PBW 621 (23.24, 25.99 kg/ha) which was significantly inferior to combination of control treatment with variety PBW 550 (26.94, 28.64 kg/ha).

**4.16 Effect on grain manganese concentration**

During both years, all the three wheat varieties proved statistically at par with each other in grain Mn concentration (Annexure XIV, Table 33).

In the treatments of nutrient management, all the treatments (except $T_3$: NPK+Cu (f) (27.97, 27.62 µg/g) were significantly higher than control (25.62, 25.25 µg/g). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (37.55, 38.46 µg/g) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (36.53, 36.44 µg/g). Further, $T_4$ was statistically at par with $T_5$: NPK+$N_{50}$+Mn (f) (34.56, 34.94 µg/g). Grain Mn concentration increased by (46.57, 52.32 %) from (25.62, 25.25 µg/g) control to (37.55, 38.46 µg/g) under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). The significant effect of foliar application of Mn is apparently visible with comparison of $T_2$: NPK+Mn (f) with NPK control. Grain Mn concentration increased by (28.34, 25.66 %) from (25.62, 25.25 µg/g) in control to (32.88, 31.73 µg/g) for $T_2$: NPK+Mn (f). Grain Mn concentration increased by (34.89, 26.50 %) from (25.62, 25.25 µg/g) in control to (34.56, 31.94 µg/g) for $T_5$: NPK+$N_{50}$+Mn (f). The increase in grain manganese concentration may be due to the combined and its synergistic effect of increased dose of nitrogen and foliar application of Mn. Similar results were reported earlier also (Dhaliwal *et al* 2011).

**4.17 Effect on straw manganese concentration**

The data in Annexure XIV, Table 33 shows that during both years, all the three wheat varieties proved statistically at par with each other in straw Mn concentration. All the treatments of nutrient management were significantly higher than control (20.17, 19.76 µg/g). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f) (37.34, 37.46 µg/g) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (35.59, 33.65 µg/g). Straw Mn concentration increased by (85.13, 89.57 %) from (20.17, 19.76 µg/g) in control to (37.34, 37.46 µg/g) in

$T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). The increase in manganese concentration in straw may be due to the combined and synergistic effect of increased dose of nitrogen as top-dressing before heading and foliar application of Mn. Similar results were reported earlier (Dhaliwal *et al* 2011).

**4.18 Effect on grain manganese uptake**

The data given in Annexure XIV, table 32 showed that during both years, Mn uptake in grain was statistically at par with all the three varieties.

All the treatments of nutrient management were significantly higher than control (74.95, 82.09 µg/g). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (203.33, 204.50 µg/g) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (192.34, 188.50 µg/g) which was significantly higher than all other treatments. The significant effect of foliar application of Mn is apparently visible with comparison of $T_2$: NPK+Mn (f) with NPK control. Grain Mn uptake increased by (108.70, 73.65 %) from (74.95, 82.09 g/ha) in control to (156.42, 142.55 g/ha) for $T_2$: NPK+Mn (f). Grain Mn uptake increased by (124.55, 107.75 %) from (74.95, 82.09 g/ha) in control to (168.30, 170.55 g/ha) for $T_5$: NPK+$N_{50}$+Mn (f). Grain Mn uptake increased by (171.29, 129.63 %) from (74.95, 82.09 g/ha) in control to (203.33, 204.50 g/ha) under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). The increase in grain manganese uptake may be due to the synergistic effect due to application of increased dose of nitrogen as top-dressing before heading and foliar application of Mn. Similar results were reported earlier (Dhaliwal *et al* 2011).

**4.19 Effect on straw manganese uptake**

Wheat varieties were statistically at par with each other for Mn uptake in straw in the first year but differed significantly in the second year (Annexure XIV, Table 32).

During both years of study, in the treatments of nutrient management of Mn uptake in straw, all the treatments were significantly higher than control (91.21, 104.31 g/ha). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (285.99, 283.98 g/ha) which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) (256.71, 257.25 g/ha) and all other treatments. Mn uptake in straw increased by (213.55, 172.25 %) from (91.21, 104.31 g/ha) in control to (285.99, 283.98 g/ha) under treatment $T_7$: NPK+N50+Mn (f)+Cu (f). Similar trends were observed for total Mn uptake in crop. Total Mn uptake in crop increased by (194.49, 163.17 %) from (166.16, 186.40 g/ha) in control to (489.32, 490.55 g/ha) in $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f). The increase in manganese uptake in straw may be due to the combined and synergistic effect of increased dose of nitrogen as top-dressing before heading and foliar application of Mn. Similar results were reported earlier (Dhaliwal *et al* 2011).

**4.20 Effect on grain copper concentration**

The data in Annexure XIV, Table 33 shows that during both years of study, all the three varieties were statistically different in grain concentration. The highest value of grain Cu concentration was recorded by variety PBW 550 (4.72, 4.03 µg/g) which was statistically at par with HD 2967 (4.65, 4.01 µg/g) but both of these varieties were significantly higher than variety PBW 621 (4.24, 3.72 µg/g). This might be due to the reason that these wheat varieties are responsive to the application of copper (Annexure XI).

All the treatments of nutrient management, (except $T_2$: NPK+Mn (f) (3.82, 3.10 µg/g) were significantly higher than control (3.40, 2.99 µg/g). The best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) (5.92, 5.82 µg/g) which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f) (5.39, 5.62 µg/g) which was significantly higher than all other treatments. The significant effect of foliar application of Cu is apparently visible with comparison of $T_3$: NPK+Cu (f) with NPK control. Grain Cu concentration significantly increased due to foliar application of copper by (26.76, 18.73 %) from (3.40, 2.99 µg/g) in control to (4.31, 3.55 µg/g) for $T_3$: NPK+Cu (f). Grain Cu concentration increased by (44.71, 38.80 %) from (3.40, 2.99 µg/g) in control to (4.92, 4.15 µg/g) for $T_6$: NPK+$N_{50}$+Cu (f). Grain Cu concentration increased by (74.12, 94.65 %) from (3.40, 2.99 µg/g) in control to (5.92, 5.82 µg/g) for treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). The increase in grain Cu concentration may be due to the combined and its synergistic effect of increased dose of nitrogen and foliar application of Cu. Similar results were reported earlier also (Dhaliwal *et al* 2011)

**4.21 Effect on straw copper concentration**

During both years of study, all the three varieties proved statistically different in grain concentration. The highest value of straw Cu concentration was recorded by PBW 550 (3.88, 3.08 µg/g) which was statistically at par with HD 2967 (3.80, 3.06 µg/g) but both of these varieties were significantly higher than PBW 621 (3.25, 2.77 µg/g). This might be due to the reason that these wheat varieties are responsive to the application of copper (Annexure XIV, Table 33).

All the treatments of nutrient management were significantly higher than control (2.41, 2.02 µg/g). The best treatment was $T_7$: NPK+N50+Mn (f)+Cu (f) (5.60, 4.88 µg/g) which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) (4.40, 3.67 µg/g) which was significantly higher than all other treatments. Straw Cu concentration increased by (132.37, 141.58 %) from (2.41, 2.02 µg/g) in control to (5.60, 4.88 µg/g) in $T_7$: NPK+N50+Mn (f)+Cu (f).

**4.22 Effect on Cu uptake in grain and straw**

Among varieities, Cu uptake in grain was significantly different in all the three varieties during both years of study. Highest Cu uptake in grain was in variety PBW 550 (21.92, 18.98

g/ha) which was at par with HD 2967 (21.39, 18.00 g/ha). Both of these varieties were significantly superior to PBW 621 (18.95, 16.86 g/ha) (Annexure XIV, Table 32).

Among wheat varieties, copper uptake in straw was statistically at par with the three bread wheat varieties in the first year but the varieties differed significantly in the second year. During the year 2012-13, the highest Cu uptake in straw was in HD 2967 (21.37 g/ha) which was significantly higher than both PBW 550 (19.49 g/ha) and PBW 621 (19.95 g/ha). PBW 550 was statistically at par with HD 2967. For wheat variety PBW 550 total Cu uptake in crop was (45.60, 38.47 g/ha), which was statistically at par with HD 2967 (45.35, 39.37 g/ha). Both PBW 550 and HD 2967 were significantly higher than PBW 621 (40.84, 36.81 g/ha) (Annexure XIV, Table 32).

All the treatments of nutrient management for Cu uptake in straw were significantly higher than control (91.21, 104.31 g/ha). The best treatment was $T_7$: NPK+N50+Mn (f)+Cu (f) (42.89, 37.00 g/ha), which was significantly higher than all other treatments. Similar trends were observed for total Cu uptake in crop. The significant effect of foliar application of Cu is apparently visible with comparison of $T_3$: NPK+Cu (f) with NPK control. Grain Cu uptake increased by (84.22, 59.05 %) from (9.95, 9.72 g/ha) in control to (18.33, 15.46 g/ha). Grain Cu uptake increased by (21.17, 21.35 %) from (18.33, 15.46 g/ha) in control to (22.21, 18.76 g/ha) for $T_6$: NPK+$N_{50}$+Cu (f). Grain Cu uptake increased by (222.21, 221.60 %) from (9.95, 9.72 g/ha) in control to (32.06, 31.26 g/ha) for treatment $T_7$: NPK+$N_{50}$ +Mn (f)+Cu (f). The increase in grain Cu uptake may be due to the synergistic effect of increased dose of nitrogen and foliar application of Cu. Similar results were reported earlier also (Dhaliwal *et al* 2011).

**4.23 Conclusions**

Among varieties, PBW 550 recorded the highest yield components and grain yield, maximum N content and uptakes in grain, straw and crop, which were significantly better than varieties PBW 621 and HD 2967 during both years of study. Wheat variety PBW 550 recorded the maximum zinc and iron concentrations and uptakes in grain and straw. Significant qualitative improvement in grain appearance score, hectolitre weight and grain hardness and SDS-Sedimentation value was observed in variety PBW 550 in comparison to PBW 621 and HD 2967 during both years of study. The variety PBW 621 was found to be significantly higher than HD 2967 in grain hardness. Both varieties PBW 621 and HD 2967 were statistically inferior to PBW 550 but at par with each other for hectolitre weight and grain appearance. The variety HD 2967 was significantly higher in β-carotene content than PBW 621 and PBW 550. The varieties PBW 621 and PBW 550 were statistically at par with each other for β-carotene content. All the three varieties were non-significant in Protein content and Phenol reaction score in both years of study.

Among the treatments of nutrient management, the best treatment was $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f), which had maximum increasing effects on straw and grain yield, N content, zinc and iron concentrations and their uptake in grain, straw and crop. Significant qualitative improvement in the physico-chemical grain characteristics was observed with application of $T_7$: NPK+$N_{50}$+Mn (f) +Cu (f) in comparison to all other treatments during both the years. All treatments of nutrient management were significantly higher than control for Protein content and grain hardness during both seasons. The highest values of grain appearance score, hectolitre weight, grain hardness, SDS-Sedimentation value and β-Carotene were observed under this best treatment for both years. The interaction effects of SDS-Sedimentation value and grain appearance score were significant during both seasons.

It can be concluded from experiment 2 that application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 DAS and foliar applications of Mn (0.5 %) and Cu (0.2 %) in the late reproductive phases (mid-boot, pre-milk and dough) enhanced. growth, yield-attributes, straw and grain yield, harvest index, nutrient concentration and uptake in grain, straw, total uptake and grain physico-chemical characters of wheat.

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## CHAPTER 5

## SUMMARY

The varietal performance in terms of growth, yield, agronomic biofortification and grain quality may change according to the genetic constitution and the agro-climatic conditions of a region. The N nutritional status of plants may greatly influence the uptake, transport, re-translocation and grain deposition of Zn, Fe and Cu (Kutman *et al* 2010). Shi *et al* (2010) reported that the N fertilization increased the concentration of the micronutrients (Zn, Fe and Cu) and protein in wheat grain. Asad *et al* (2000) studied that the combined effect of Zn, Fe, Cu and Mn increased wheat dry matter, straw yield and grain yield significantly over control.

The present study entitled, **"Agronomic biofortification and enhancement of productivity in bread wheat (*Triticum aestivum* L.) varieties"** was conducted at Punjab Agricultural University, Ludhiana during *rabi* 2011-12 and 2012-13 under timely-sown, irrigated-conditions on loamy-sand soil (*Typic Ustochrept*) testing near normal in pH, low EC, low in available N, medium in available P and K, low in available Cu and Mn. The experiment I was laid out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient management treatments ($T_1$: NPK alone as control, $T_2$: NPK+Mn (f), $T_3$: NPK+Cu (f), $T_4$: NPK+Mn (f)+Cu (f), $T_5$: NPK+$N_{50}$+Mn (f), $T_6$: NPK+$N_{50}$+Cu (f) and $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) in the sub plots. The experiment II was also laid-out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with nine nutrient treatments $T_1$: NPK (Control), $T_2$: NPK+Zn (s), $T_3$: NPK+Zn (f), $T_4$: NPK+Zn (s)+Zn (f), $T_5$: NPK+Fe (f), $T_6$: NPK+Zn (s)+$N_{50}$, $T_7$: NPK+$N_{50}$+Zn (f), $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) and $T_9$: NPK+$N_{50}$+Fe (f) in the sub-plots.

Three wheat varieties were sown on dated 6-7 November 2011 and 2012. Nitrogen (N) was applied @ 125 kg/ha as urea in 3 splits (1/2 at sowing, 1/4 after first irrigation and 1/4 after second irrigation). Phosphorous ($P_2O_5$) @ 62.5 kg/ha as DAP and potassium ($K_2O$) @ 30 kg/ha as MOP was applied as full basal dose before sowing. An additional dose of N @ 50 kg/ha was applied as top-dressing 80 DAS (before heading). Three foliar sprays of 0.5 % $ZnSO_4$. $7H_2O$ and $FeSO_4$. $7H_2O$ were done for experiment I and three foliar sprays of 0.5 % $MnSO_4$. $H_2O$ and 0.1 % $CuSO_4$. $5H_2O$ were done for experiment II separately at three grain development stages such as mid-boot, pre-milk and dough stage. All foliar sprays contained 0.01 % (v/v) Tween as a surfactant to enhance the penetration of foliar fertilization through cuticle of leaf surface. The results of experiment 1 are summarized below:

**Effect of varieties**

Among wheat varieties, at 60 DAS, plants of all varieties were statistically at par with each other for height, dry matter accumulation and LAI. The variety PBW 550 was

significantly taller than HD 2967 and PBW 621 at 90 DAS. Plant height of HD 2967 and PBW 621 varieties was statistically at par with each other. At 120 DAS and at harvest, the plant height of variety PBW 550 recorded was found to be lowest which was significantly lower than other varieties. Dry matter accumulation of variety PBW 550 was significantly higher at 90 DAS but it was significantly higher in variety PBW 621 at 120 DAS. The varieties HD 2967 and PBW 621 were found to be statistically at par with each other except for 120 DAS. LAI of three varieties was statistically at par with each other at 60 DAS. The wheat variety PBW 550 resulted in significantly higher LAI than variety PBW 621 at 90 DAS but significantly lower than PBW 621 and HD 2967 at 120 DAS. LAI of variety PBW 621 was significantly higher than PBW 550 and HD 2967.

Number of effective tillers/$m^2$ were lowest in variety PBW 550 than PBW 621 and HD 2967 varieties however it was statistically at par with variety HD 2967. The variety PBW 550 had significantly higher number of grain/ear and thousand grain weight and HI over all other varieties during both seasons. The variety PBW 621 and HD 2967 were statistically at par for ear length. The variety PBW 550 produced the highest grain yield which was significantly higher than HD 2967. The varieties PBW 550 and PBW 621 were statistically at par for grain yield. The variety PBW 550 produced the lowest straw yield which was significantly inferior to PBW 621.

The variety PBW 550 recorded the maximum qualitative improvement in protein content, grain appearance score, grain hardness and hectolitre weight (except Phenol Reaction Score and β-Carotene), which were significantly better than varieties PBW 621 and HD 2967 during both years of study. The highest grain and straw Zn concentration was found in variety PBW 550 which was significantly higher than PBW 621 followed by statistically inferior variety HD 2967. Highest Zn uptake in grain was in variety PBW 550 followed by HD 2967 followed by PBW 621. Straw Zn uptake was statistically superior in PBW 550 than HD 2967 during both the years. Total uptake was highest in the variety PBW 621 which was statistically at par with PBW 550 but significantly higher than HD 2967.

Highest Zn and Fe concentration in grain and straw was recorded by variety PBW 550, which was significantly higher than varieties PBW 621 and HD 2967. Highest Fe uptake in grain was in variety PBW 621 followed by significantly inferior variety PBW 621 which was statistically at par with HD 2967. Iron uptake in straw and total uptake were superior in variety PBW 621 which was followed by HD 2967 which were significantly higher than PBW 550 during both the years.

Nitrogen content in grain and straw was significantly higher in the variety PBW 550 which was significantly higher than PBW 621. Variety PBW 621 was significantly superior to HD 2967 for grain N content. Variety PBW 621 was statistically at par with HD 2967 for

straw N content. Grain N uptake in variety PBW 550 was significantly higher than HD 2967 but statistically at par with PBW 621. Grain N uptake among three varieties was statistically non-significant in the 2nd year. Total N uptake by crop was statistically non-significant among three varieties during both cropping seasons.

**Effect of nutrient management treatments**

The varieties PBW 621 and HD 2967 were statistically at par for height at 90, 120 DAS and at harvest,. All nutrient treatments were statistically significant in height than control at all the stages except at 60 DAS. At 90 DAS, $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f) and $T_7$: NPK+$N_{50}$+Zn (f), but significantly higher than $T_6$: NPK+Zn (s)+$N_{50}$. For periodic dry matter, in the treatments of nutrient management, at 90 DAS and 120 DAS, $T_8$: NPK + Zn (s) + $N_{50}$ + Zn (f) was the best treatment which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f). The treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) recorded significantly higher LAI than all the treatments. The second best treatment was $T_4$: NPK+Zn (s)+Zn (f).

For periodic tiller count, at 60 DAS, Treatments $T_1$: NPK (Control), $T_3$: NPK+Zn (f), $T_5$: NPK+Fe (f), $T_7$: NPK+$N_{50}$+Zn (f) and $T_9$: NPK+$N_{50}$+Fe (f) were statistically at par with each other and treatments $T_2$: NPK+Zn (s), $T_4$: NPK+Zn (s)+ Zn (f), $T_6$: NPK+Zn (s)+$N_{50}$ and $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) were statistically at par with each other. The maximum tillers were produced at 90 DAS with the treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) which were significantly higher than all other treatments. For effective tillers, ear length, grains/ear all the treatments proved significantly higher than control. The maximum effective tillers were produced with the combined treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f)]. For TGW, all the treatments proved significantly higher than control. $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment which was statistically at par with $T_4$: NPK+Zn (s)+Zn (f).

For grain yield the treatment $T_8$: NPK+Zn (s)+$N_{50}$ + Zn (f) was the best treatment which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f), which was statistically at par with $T_7$: NPK+$N_{50}$+Zn (f) and $T_6$: NPK+$N_{50}$+Zn (s). For straw yield, all the treatments proved significantly higher than control except $T_2$: NPK+Zn (s). The treatment NPK+Zn (s)+$N_{50}$+Zn (f) was the best treatment, which was significantly higher than $T_4$: NPK+Zn (s)+Zn (f), which was statistically at par with $T_7$: NPK+$N_{50}$+Zn (f), $T_6$: NPK+$N_{50}$+Zn (s) and $T_3$: NPK+Zn (f). For HI, all the treatments proved significantly higher than control.

For grain appearance score, hectolitre weight and grain hardness, all the treatments of nutrient management were significantly higher than control. The maximum values of protein content, sedimentation values and β-carotene were recorded for the treatment $T_8$: NPK+Zn

(s)+$N_{50}$+Zn (f) . Phenol Reaction Score was found non-significant in all the three varieties, nutrient treatments and their interaction in both years.

Grain Zn concentration and uptake was highest in treatment $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) which was statistically at par with $T_4$: NPK+Zn (f)+Fe (f). For grain Zn uptake, all the treatments were significantly higher than control. Similar trends were observed for Zn uptake in straw and total Zn uptake in crop. For Fe grain concentration and uptake, the treatment $T_9$: NPK+$N_{50}$+Fe (f) was significantly higher than $T_5$: NPK+Fe (f). For straw Fe concentration and uptake the treatment $T_9$: NPK+$N_{50}$+Fe (f) was significantly higher than $T_5$: NPK+Fe (f). Similar trends were observed for total Fe uptake in grain, straw and total uptake by crop.

Highest N content and uptake in grain, straw and crop was recorded for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) in grain N content, uptake in grain, straw uptake and total N uptake by crop which was significantly higher than control. Interaction effect of wheat varieties and nutrient treatments on grain N content and straw N uptake were found to be significant. However, the other interaction effects were non-significant.

**Results of experiment 2**

**Effect of varieties**

At 60 DAS, plants of all varieties were statistically at par with each other for periodic plant height, dry matter and LAI. At 90 DAS, variety PBW 550 was significantly taller than HD 2967 and PBW 621. At 120 DAS and at harvest, the plant height of variety PBW 550 recorded was significantly lower than other varieties. At harvest, both varieties PBW 621 and HD 2967 were statistically at par with each other for plant height but significantly higher than PBW 550. The variety PBW 550 produced significantly lower dry matter accumulation than PBW 621, which was statistically at par with variety HD 2967.

The variety PBW 550 recorded significantly lower LAI than PBW 621 which was significantly higher than HD 2967. For tiller count, the variety PBW 621 was statistically at par with HD 2967 but significantly higher than PBW 550 at 90 and 120 DAS. During both years, PBW 621 produced the highest number of effective tillers, which was significantly higher than PBW 550 but statistically at par with HD 2967. The variety PBW 550 produced significantly higher ear length than PBW 621 and HD 2967. The varieties PBW 621 and HD 2967 were statistically at par with each other in ear length. PBW 550 produced the highest number of grains/ear which was significantly higher than PBW 621 and HD 2967. PBW 621 and HD 2967 were statistically at par with each other. All the three varieties were statistically at par with each other for grain, straw yield and Mn concentration in grain and straw. The variety PBW 550 had significantly higher HI followed by varieties HD 2967 and PBW 621.

The variety PBW 550 had significantly higher grain appearance score, hectolitre weight and grain hardness and sedimentation values than both varieties PBW 621 and HD 2967. The variety PBW 621 was statistically at par with HD 2967. The protein content values and phenol reaction score were statistically non-significant for the three varieties. The highest β-carotene content was recorded in variety HD 2967 which was significantly higher than variety PBW 550. The variety PBW 550 was statistically at par with PBW 621 in β-carotene content.

The highest Mn uptake in straw was in variety PBW 621 which was significantly higher than PBW 550 but statistically at par with HD 2967.The highest value of grain Cu concentration was recorded by variety PBW 550 which was statistically at par with HD 2967 but both of these varieties were significantly higher than PBW 621. Highest Cu uptake in grain was in variety PBW 550 followed by HD 2967 followed by PBW 621. The highest Cu uptake in straw was in HD 2967 which was significantly higher than both PBW 550 and PBW 621. The variety PBW 550 was statistically at par with HD 2967 for Cu uptake in straw. Total Cu uptake in crop was highest in variety PBW 550 which was statistically at par with HD 2967. The variety PBW 550 recorded the highest total uptake in crop followed by PBW 621 followed by HD 2967.

**Effect of nutrient management treatments**

For plant height, all nutrient treatments were significantly superior in height than control. $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment, which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f), which was further statistically at par with $T_5$: NPK+$N_{50}$+Mn (f) but significantly higher than $T_2$: NPK+Mn (f) and $T_3$: NPK+Cu (f). For dry matter, $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f) which was significantly higher than all other treatments. The treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) recorded significantly higher LAI than all other treatments. The second best treatment was $T_4$ [NPK+Mn (f)+Cu (f)].

The maximum number of tillers were produced at 90 DAS with the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). Tiller count, effective tillers, ear-length, grains/ear, TGW, grain and straw yield and HI in all the treatments were significantly higher than control. The maximum effective tillers were produced with the treatment $T_7$: NPK+ $N_{50}$+Mn (f)+Cu (f) which was significantly higher than $T_4$ [NPK+Mn (f)+Cu (f)]. For ear length and grains/ear and thousand grain weight, $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f). For grain yield, $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment, which was significantly higher than $T_4$: NPK+Mn (f)+Cu (f). The treatment $T_4$ was statistically at par with $T_5$: NPK+$N_{50}$+Mn (f). For straw yield, $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) was the best treatment which was statistically at par with $T_4$:

NPK+Mn (f)+Cu (f). For HI, In the first year, $T_4$ : NPK+$N_{50}$+Mn (f) was statistically at par with $T_7$ : NPK+$N_{50}$+Mn (f)+Cu(f). The treatment $T_7$: NPK+$N_{50}$+Mn (f) + Cu (f) produced the highest HI in the second year which was significantly higher than all the other treatments.

The maximum grain appearance score was in the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than $T_5$: NPK+$N_{50}$+Mn (f) followed by $T_6$: NPK+$N_{50}$+Cu (f) which was statistically at par with $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). The highest hectolitre weight was recorded for the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was statistically at par with the treatment $T_5$: NPK+$N_{50}$+Mn (f), $T_6$: NPK+$N_{50}$+Cu (f) and $T_4$: NPK+Mn (f)+Cu (f). The highest grain hardness was recorded under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than the treatment $T_5$: NPK+$N_{50}$+Mn (f). The treatment $T_5$ was statistically at par with the treatment $T_6$: NPK+$N_{50}$+Cu (f). The treatment $T_6$ was statistically at par with $T_4$: NPK+Mn (f)+Cu (f).

The highest values of protein content were recorded under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than the treatment $T_5$: NPK+$N_{50}$+Mn (f) which was statistically at par with both the treatments like $T_6$: NPK+$N_{50}$+Cu (f) and $T_4$: NPK+Mn (f)+Cu (f). During both years, the peak values of sedimentation value were recorded under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than $T_5$: NPK+$N_{50}$+Mn (f) .During both the years, the highest values of β-carotene were recorded under the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) which was significantly higher than the treatment $T_5$: NPK+$N_{50}$+Mn (f), which was statistically at par with $T_6$: NPK+$N_{50}$+Cu (f), which was statistically at par with $T_4$: NPK+Mn (f)+Cu (f). For sedimentation value and β-carotene all treatments of nutrient management were significantly higher than control. Phenol Reaction Score was non-significant among all the three varieties, nutrient treatments and their interaction in both years. Mn uptake in grain was statistically at par among all the three varieties. Mn, Cu concentration and N content, in grain and straw and their uptake by crop were maximum in the treatment $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f). Interaction effect of wheat varieties and treatments nutrient management on nitrogen content, uptake in grain and total N uptake by crop was non-significant. However, the interaction effect of N content in straw and its uptake was significant.

**Conclusions**

Grain yield increased by (54.67, 70.94 %) from control values (36.11, 33.07 q/ha) to $T_8$: NPK + Zn (s) + $N_{50}$ + Zn (f) (55.85, 56.53 q/ha). Grain Zn concentration increased by (56.47, 62.81%) from (23.64, 22.48 µg/g) of control to (36.99, 36.60 µg/g) for $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f). Grain Fe concentration increased by (38.71, 19.33 %) from (31.31, 30.67 µg/g) in control to (43.43, 43.04 µg/g) in $T_8$. In the experiment II, grain yield increased by (85.1, 65.21 %) from (29.25, 32.51 q/ha) in control to (54.15, 53.71 q/ha) for best treatment

$T_7$: NPK + $N_{50}$ + Mn (f) + Cu (f). Grain Mn concentration increased by (46.57, 52.32 %) from (25.62, 25.25 µg/g) control to (37.55, 38.46 µg/g) in $T_7$. Grain Cu concentration increased by (74.11, 94.65 %) from (3.40, 2.99 µg/g) in control to (5.92, 5.82 µg/g) in $T_7$.

Hence, it can be concluded from the experiment 1 that application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 DAS in combination with soil application of zinc sulphate @62.5 kg/ha and three foliar sprays of 0.5 % $ZnSO_4$. $7H_2O$ and 0.5 % $FeSO_4$. $7H_2O$ are beneficial in improving growth, yield, uptake of nitrogen, agronomic biofortification of zinc and iron and overall grain quality.

It can be concluded from experiment 2 that application of nitrogen @ 125 kg/ha applied as three splits (1/2 sowing + 1/4 after first irrigation and 1/4 after second irrigation) and top-dressing @ 50 kg/ha 80 DAS and foliar applications of Mn (0.5 %) and Cu (0.2 %) in the late reproductive phases (mid-boot, pre-milk and dough) enhanced. growth, yield-attributes, straw and grain yield, harvest index, nutrient concentration and uptake in grain, straw, total uptake and grain physico-chemical characters of wheat. Agronomic biofortification is indeed the key to enhancement in growth, productivity and overall quality of bread wheat and thereby helps in removing the hunger and malnutrition in the masses.

## References

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Shi R, Jhang Y, Chan X, Sun Q, Zhang F, Romheld V and Zou C (2010) Influence of long-term nitrogen fertilization on micronutrient density in grains of winter wheat (*Triticum aestivum* L.) *J Cereal Sci* **51** : 165-70.

Welch R M (2005) Biotechnology, biofortification and global health. *Food Nutr Bull* **26** : 419-21.

**ANNEXURE I**

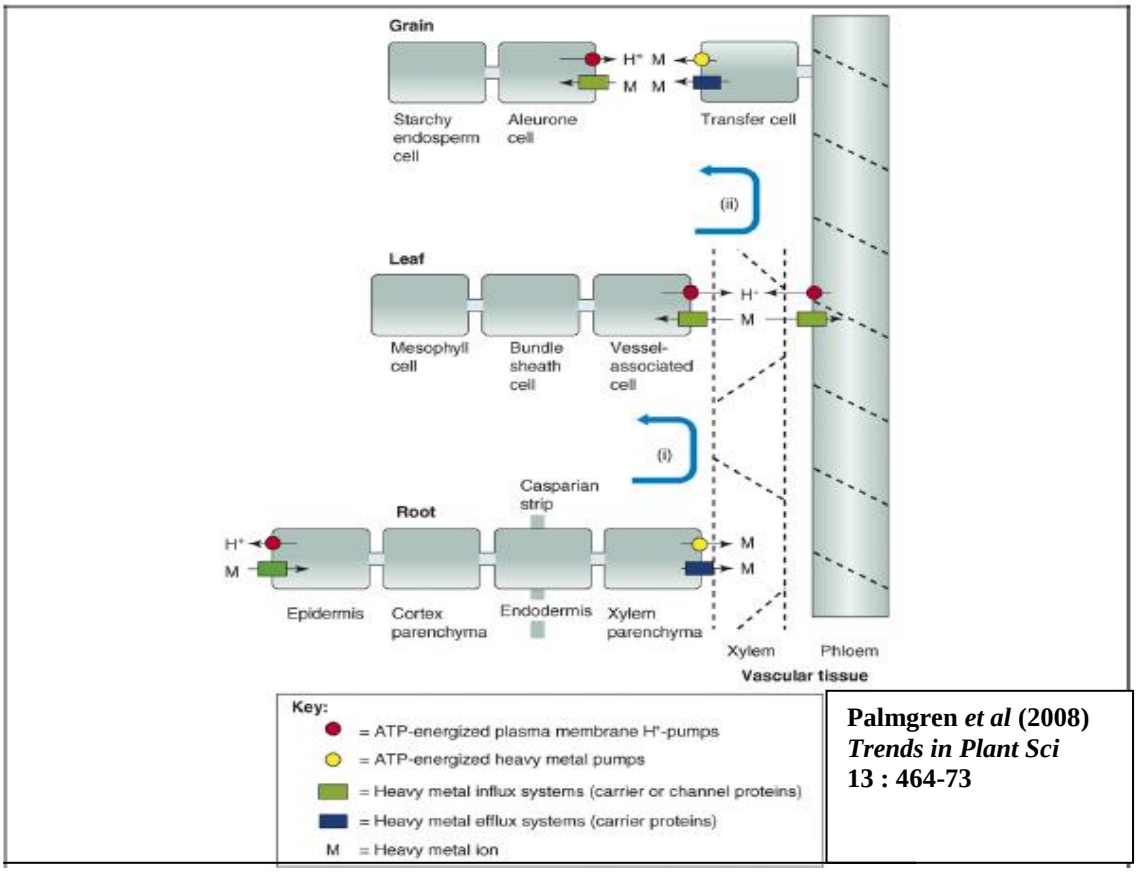



**Figure 1: Mechanism of the transport pathway of a metal ion from soil to grain**

To reach the grain, nutrients enter and leave the symplastic cells within the plant. Plant roots contribute to making metal ions more available for uptake by two strategies. First, depending upon the nutrient status of the soil, roots acidify the rhizosphere through plasma membrane $H^{+}$-ATPases, proton pumps in the cell membrane. An increased proton concentration in the soil results in cation exchange and release of divalent metal cations held tightly by the soil. Second, roots actively secrete metal chelaters (organic acids and phytosiderophores) in the soil. Secreted phytosiderophores are known to facilitate uptake of $Fe^{2+}$ and $Zn^{2+}$ by graminaceous plants. After entry of metal ions in to root cells by transport-protein-mediated processes, they migrate by diffusion to xylem parenchyma cells, from where they are actively transported out of the symplast into the dead xylem. In the roots, they are again taken to vessel-associated cells in the leaves. During the period of grain-filling, metal ions are remobilized in leaves, from where they are exported and transported via the phloem to the grain by specialized metal transport proteins.

**ANNEXURE II**

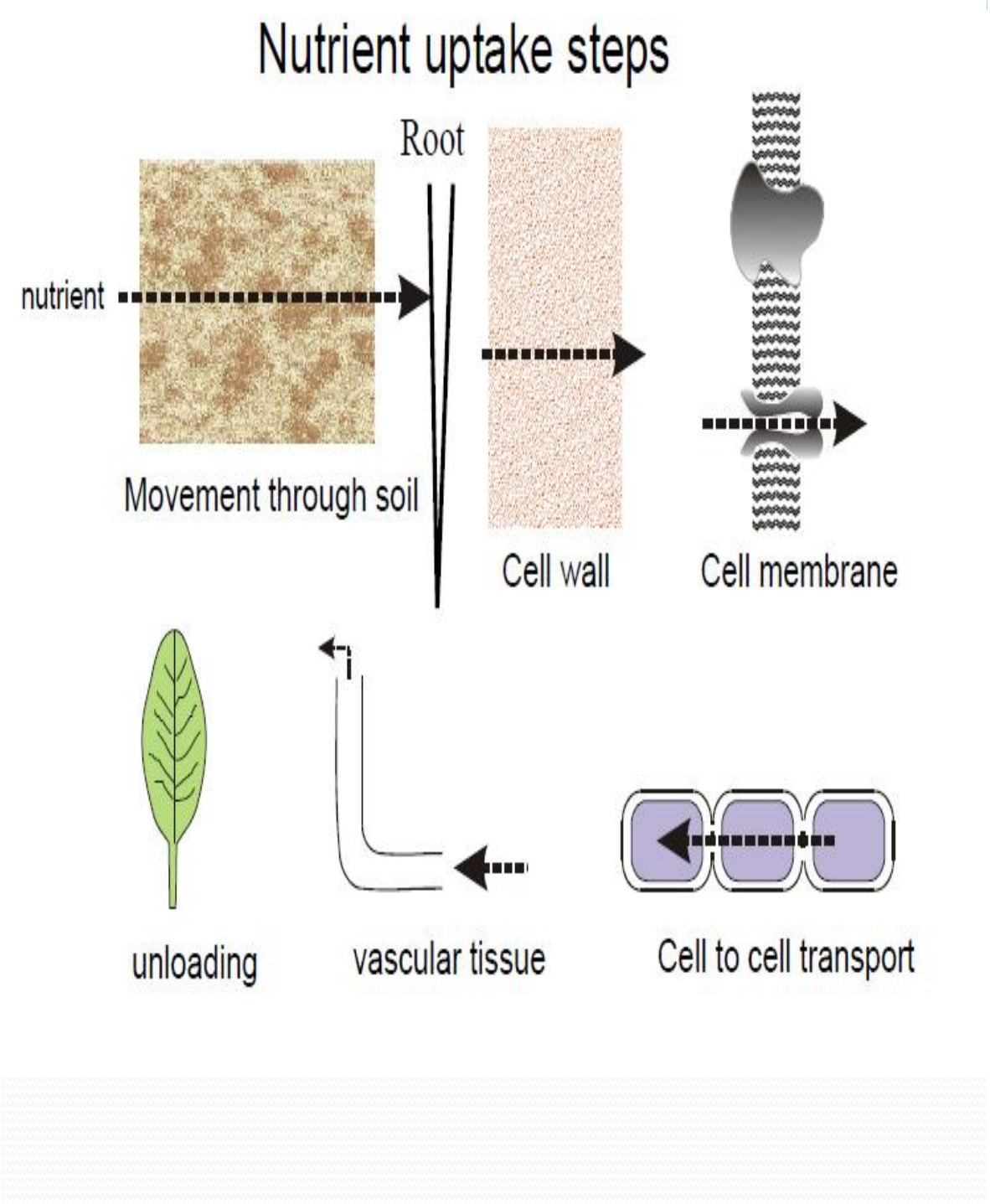



**Fig. 2 Various steps of pathway of nutrients from soil-roots-cell**

**ANNEXURE III**

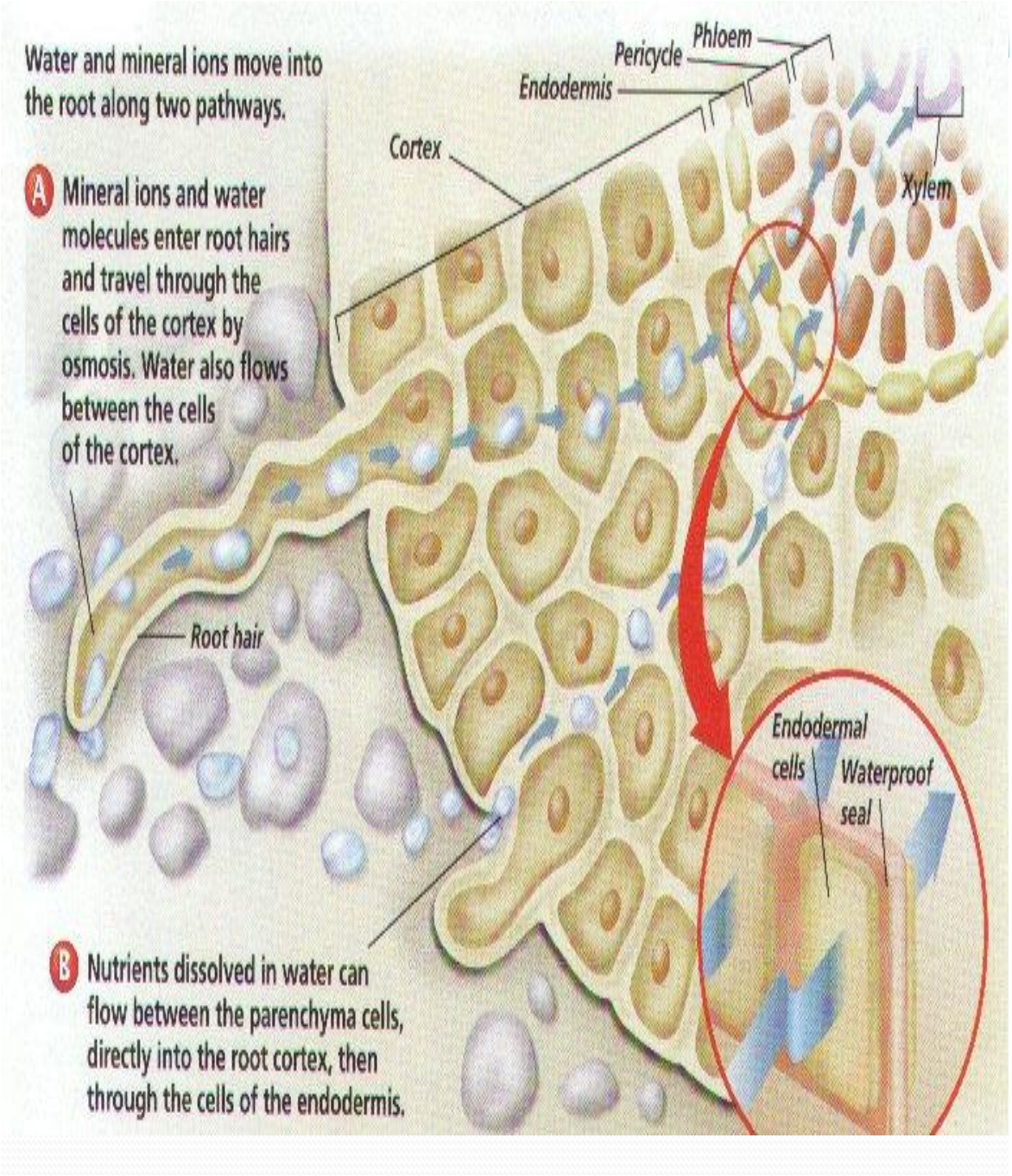



**Fig. 3 Pathways of water and mineral ions inside the root**

**ANNEXURE IV**

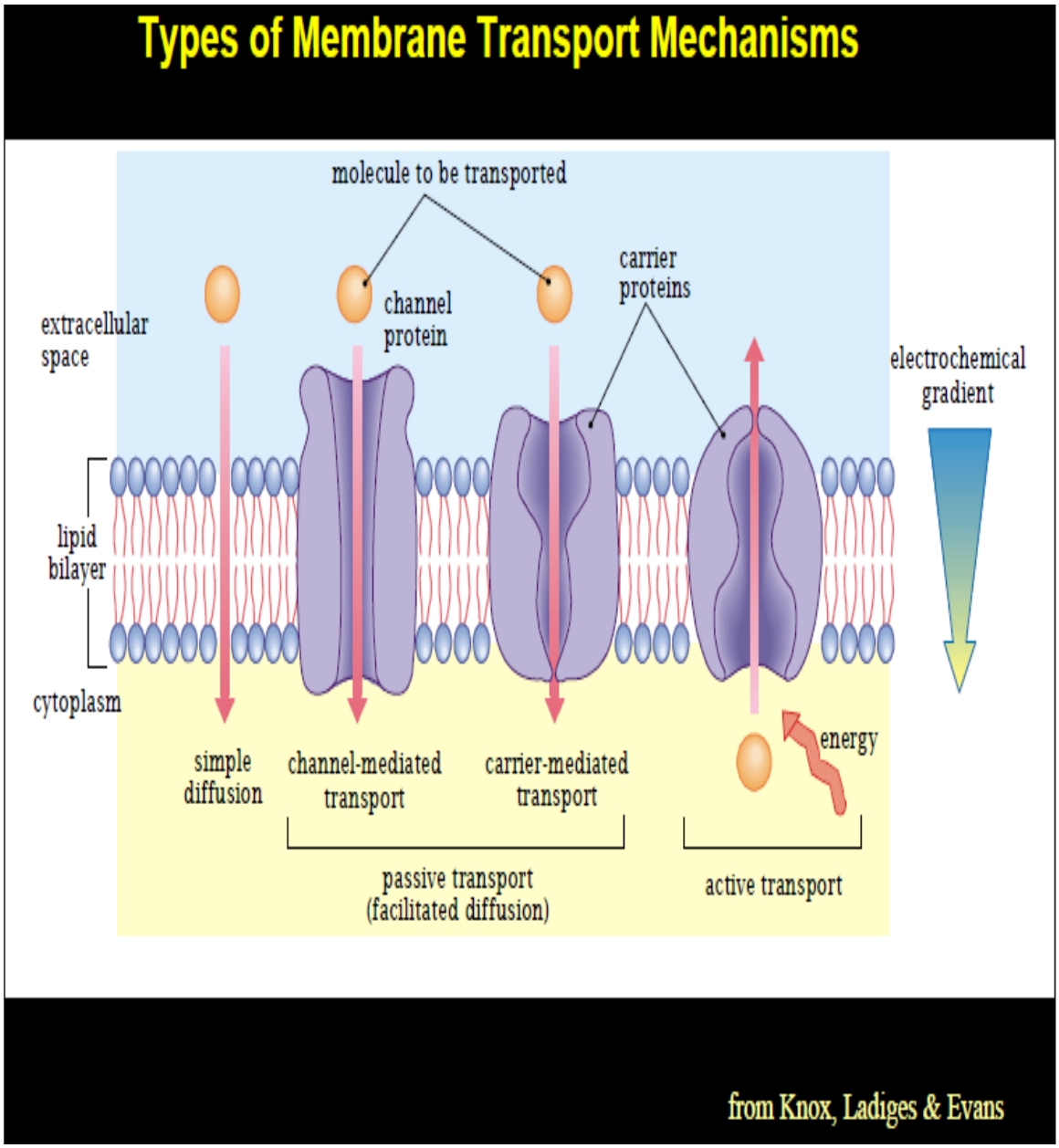
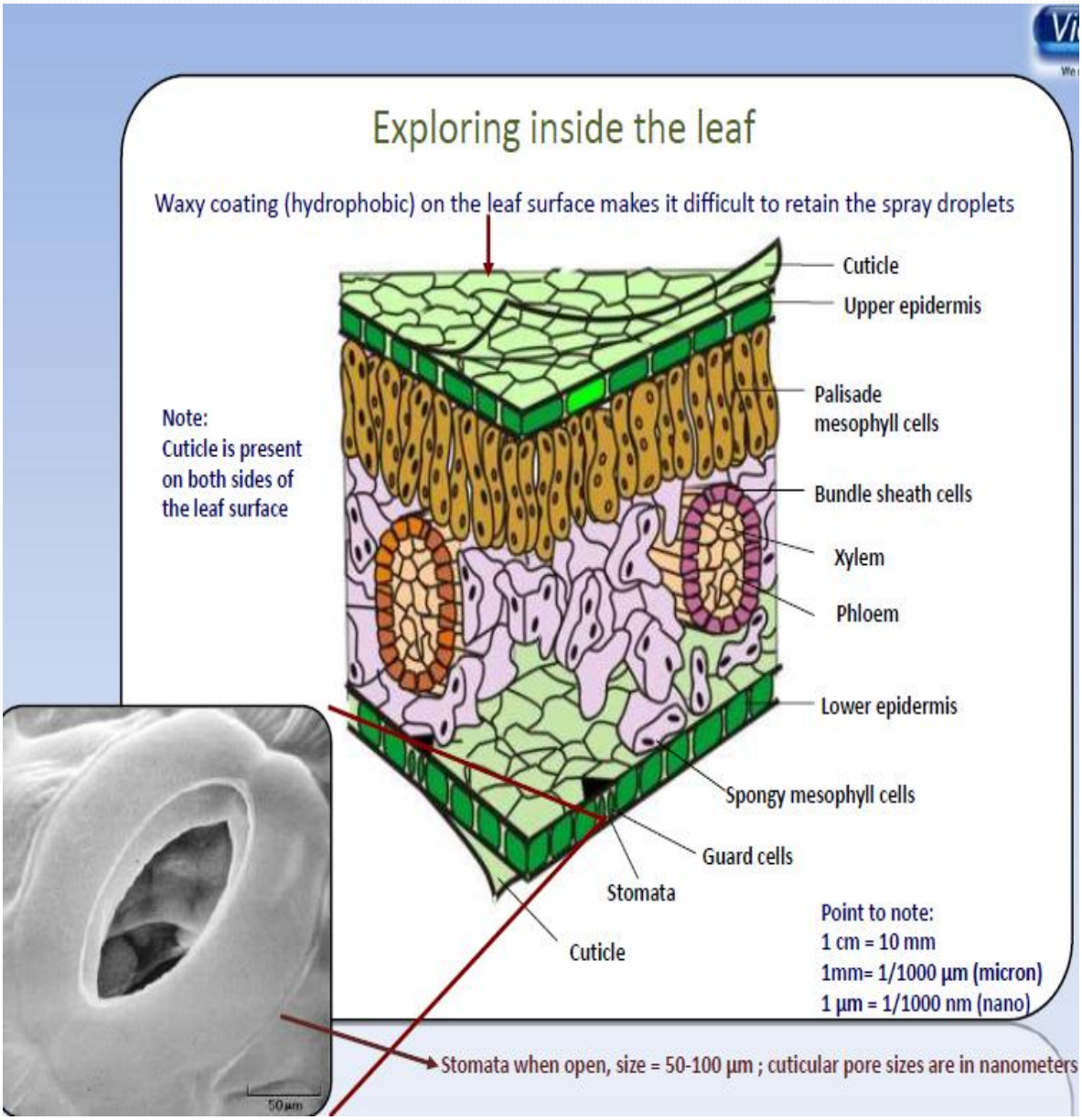



**Fig 4. Types of membrane transport mechanisms**

**ANNEXURE V**

**FIG 5. FOLIAR NUTRITION DECREASES THE LAG TIME BETWEEN NUTRIENT UPTAKE BY ROOTS AND TRANSLOCATION FROM SOURCE TO THE SINK BY BYPASSING THE BARRIERS IN NUTRIENT UPTAKE OF MICRONUTRIENTS**



**ANNEXURE VI**

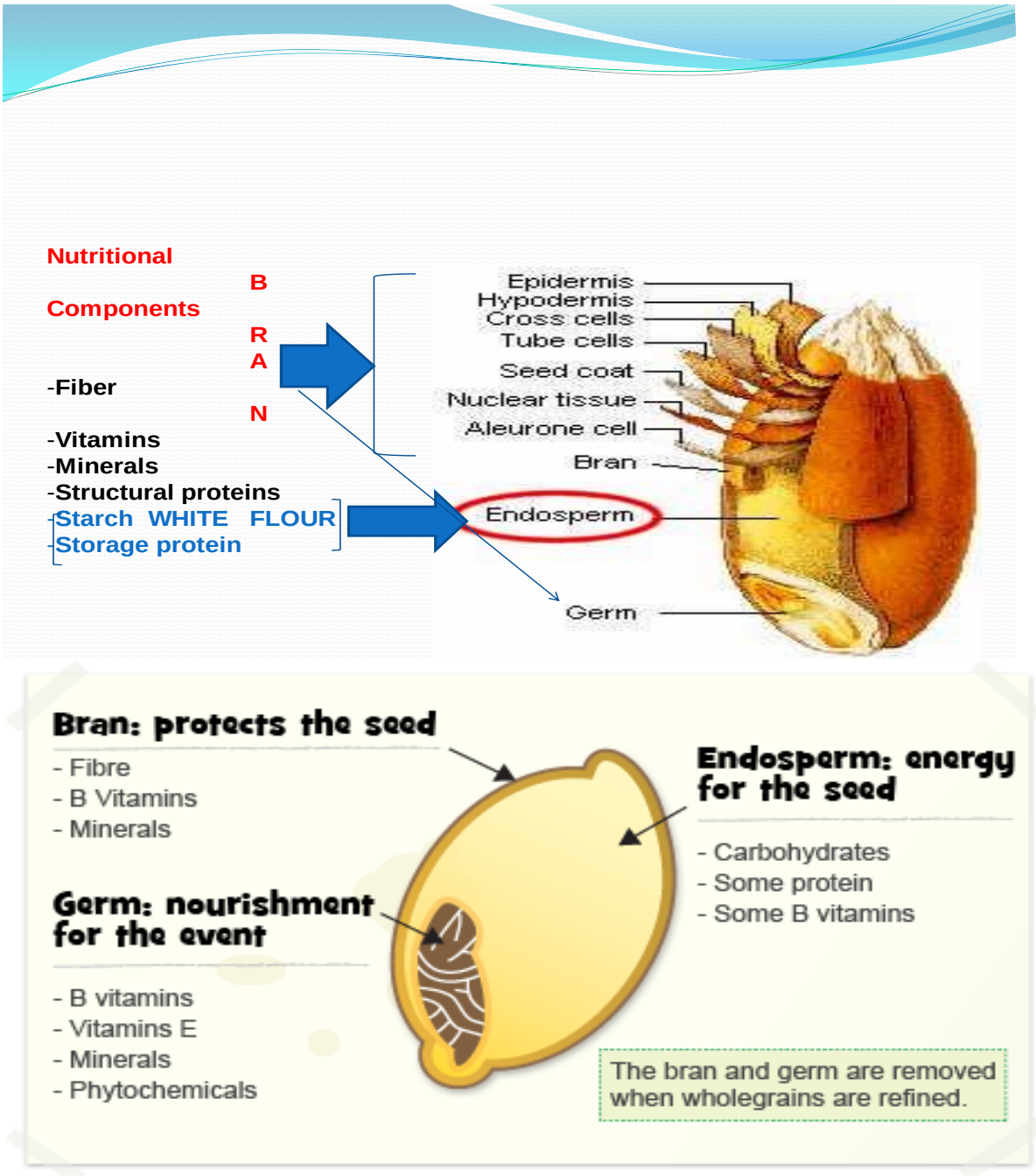
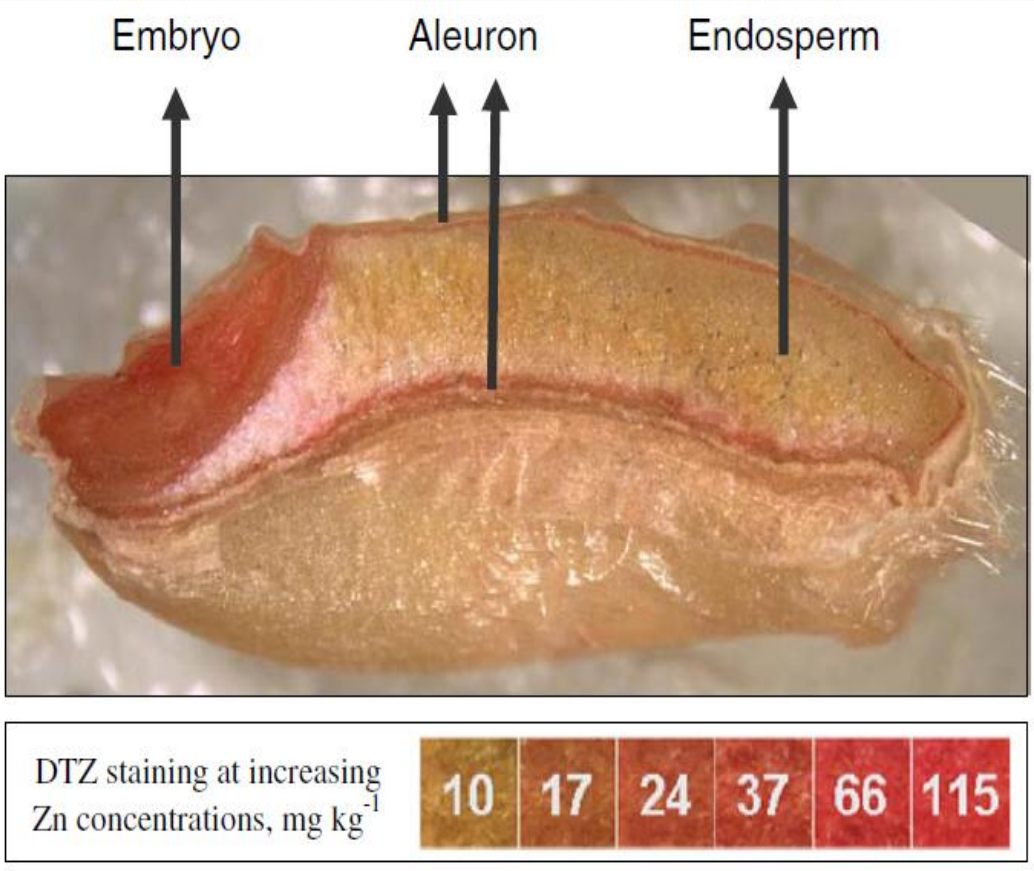



**Fig 6. Internal structure of wheat grain**

**ANNEXURE VII**

**FIG 7. DTZ ( DIPHENYL THIOCARBAMATE ZONE) STAINING A WHEAT SEED WHEN REACTING WITH ZINC. DTZ FORMS A RED DTZ-COMPLEX INDICATING LOCALIZATION OF ZINC (FOR DETAILS SEE : Ozturk *et al* 2006)**




Cakmak (2008), Plant Soil 302: 1-17

**ANNEXURE VIII**

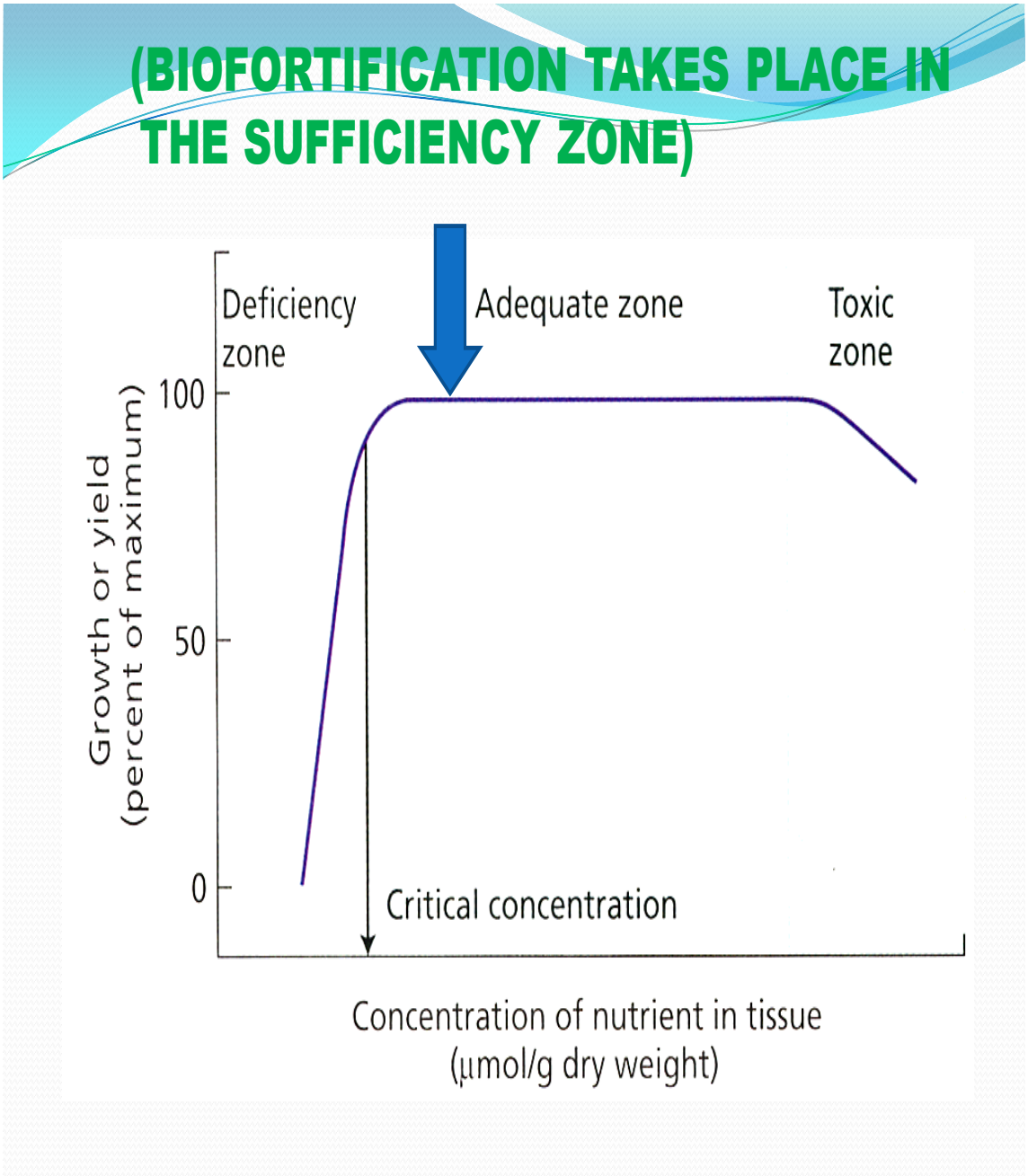



**Fig 7. Fertiliser dose-response curve**

**ANNEXURE IX**

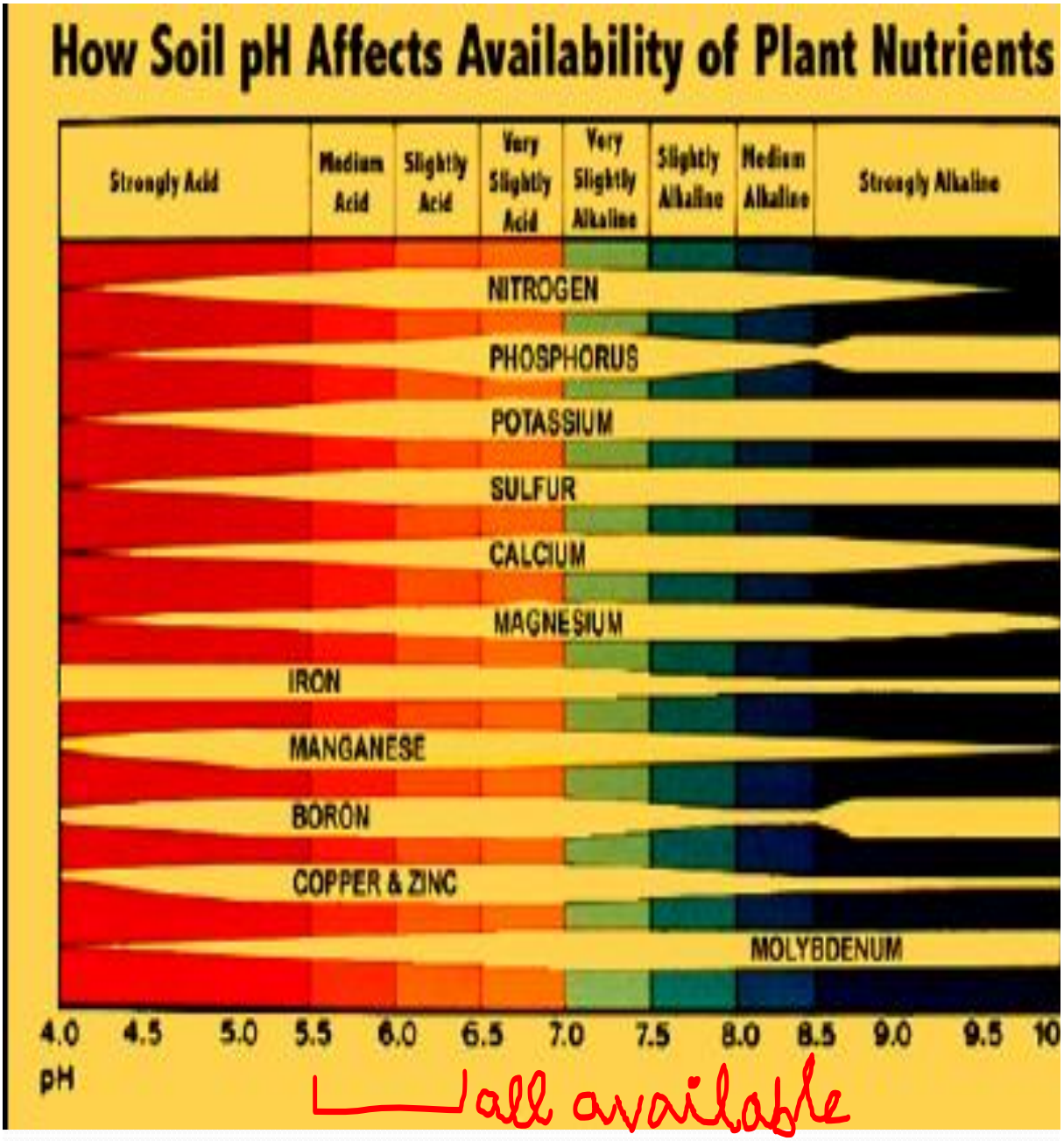



**Fig 8. Effect of soil pH on availability of nutrients**

**ANNEXURE X (a,b)**

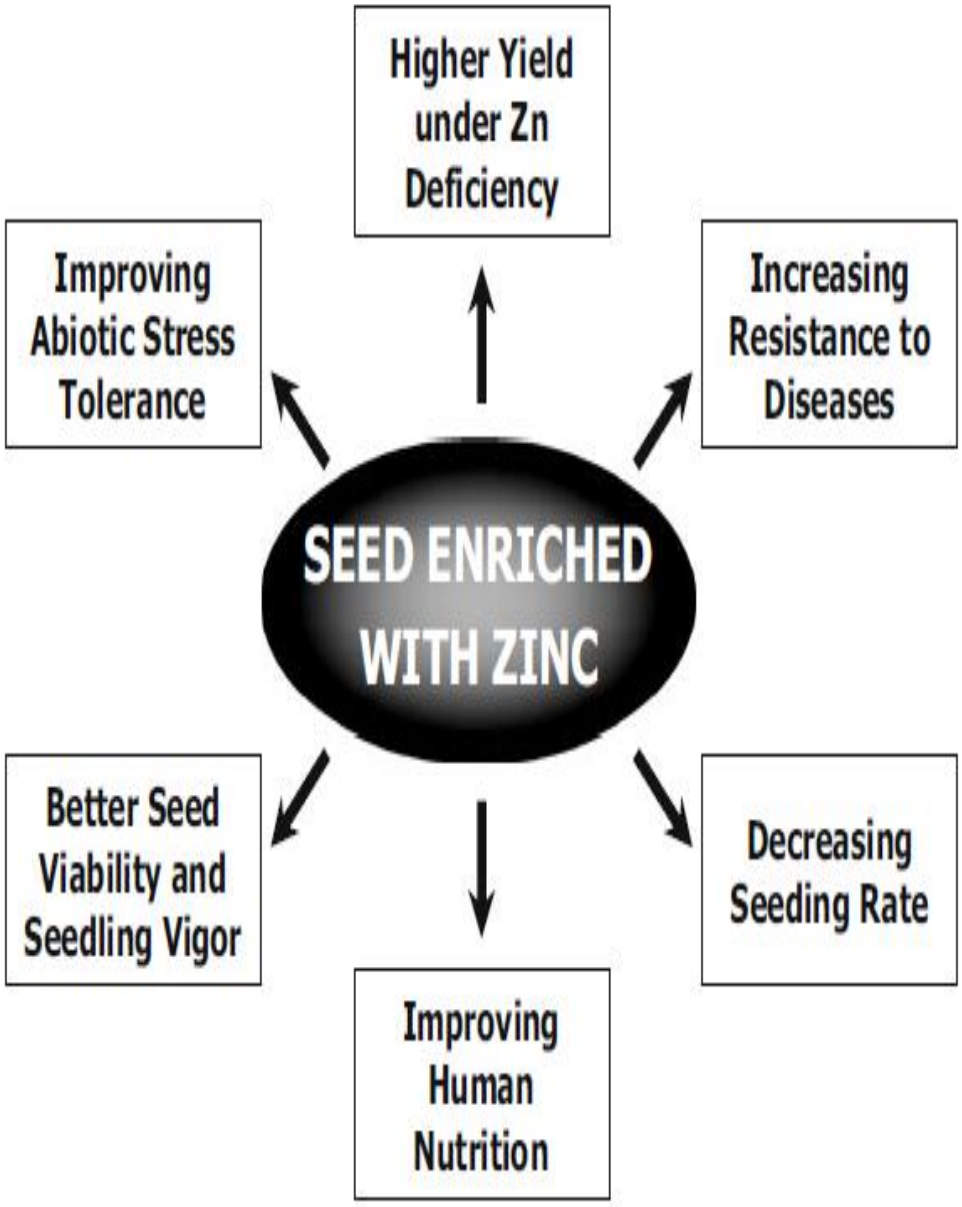
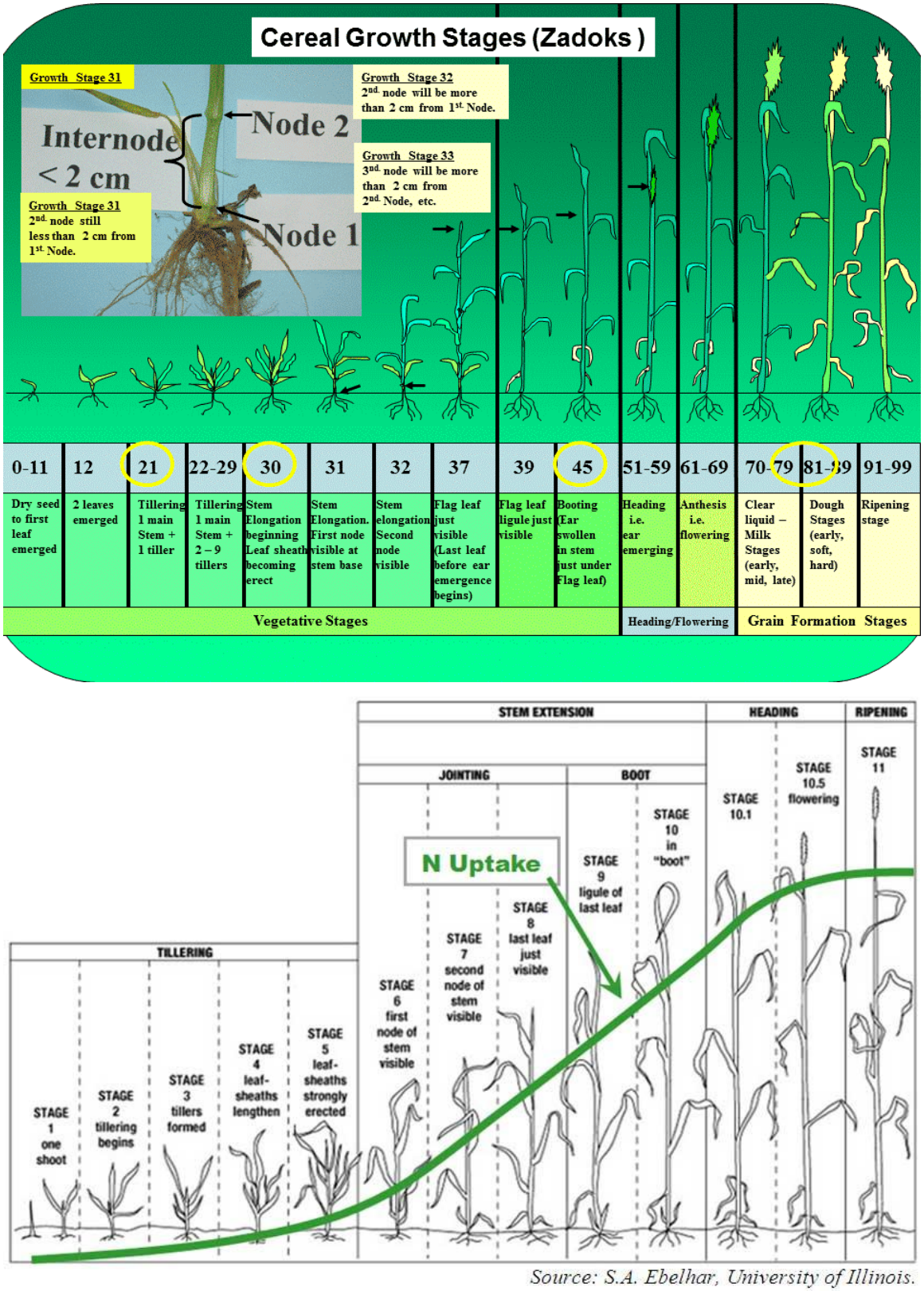



**Fig 9. Agronomic benefits of seed enriched with zinc**







*Source: S.A. Ebelhar, University of Illinois.*

**Fig 10. Zadoks (Europe) and Feekes (US) scales of wheat showing various growth stages**

## ANNEXURE XI

### Weekly standard meteorological data recorded during crop season *rabi* 2011-12

| Standard Meteorological Week | Temperature (°C) | | | Relative Humidity (%) | | | Total Rainfall (mm) | Total Evaporation (mm) | SSH (hr) |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Mean | Morn. | Even. | Mean | | | |
| 45 (5-11 Nov.) | 28.27 | 14.06 | 21.16 | 91 | 43 | 67 | 0 | 2.4 | 6.38 |
| 46 (12-18 Nov.) | 28.3 | 12.5 | 20.4 | 95 | 38 | 67 | 0 | 17.1 | 8.1 |
| 47 (19-25 Nov.) | 27.1 | 12.4 | 19.8 | 98 | 55 | 77 | 0 | 12.1 | 0.9 |
| 48 (26-02 Dec.) | 24.6 | 9.8 | 17.2 | 97 | 46 | 72 | 0 | 11.3 | 4.6 |
| 49 (03-09 Dec.) | 25.4 | 12.2 | 18.8 | 93 | 50 | 71 | 11.4 | 13.6 | 6.4 |
| 50 (10-16 Dec.) | 20.9 | 6 | 13.5 | 99 | 49 | 74 | 0 | 7.7 | 7.6 |
| 51 (17-23 Dec.) | 19.4 | 4.3 | 11.8 | 99 | 47 | 73 | 0 | 9.2 | 6.2 |
| 52 (24-31 Dec.) | 20.1 | 3.1 | 11.6 | 99 | 46 | 73 | 0 | 8.6 | 6.5 |
| 1 (01-07 Jan) | 17.1 | 7.3 | 12.2 | 97 | 72 | 83 | 13 | 8.8 | 2.5 |
| 2 (08-14 Jan) | 16.6 | 3 | 9.8 | 99 | 56 | 78 | 2 | 1.3 | 8.6 |
| 3 (15-21 Jan) | 14.3 | 7.7 | 11 | 94 | 83 | 89 | 38 | 1 | 2 |
| 4 (22-28 Jan) | 18.4 | 5.4 | 11.9 | 92 | 46 | 69 | 0 | 1.3 | 9.3 |
| 5 (29-04 Feb) | 21.7 | 6.1 | 11.3 | 96 | 45 | 78 | 0 | 1.9 | 6.3 |
| 6 (05-11 Feb) | 17.8 | 4.2 | 13.9 | 94 | 41 | 71 | 0 | 14.5 | 7.6 |
| 7 (12-18 Feb) | 19.7 | 6.7 | 13.2 | 89 | 49 | 69 | 12 | 16.6 | 5.8 |
| 8 (19-25 Feb) | 20.9 | 8.1 | 14.5 | 89 | 52 | 71 | 0 | 16.2 | 6.5 |
| 9 (26-04 Mar) | 24.1 | 8.4 | 13.3 | 90 | 41 | 69 | 0 | 32.1 | 8.9 |
| 10 (05-11 Mar) | 24.5 | 10.1 | 17.3 | 90 | 41 | 66 | 0 | 24.5 | 8 |
| 11 (12-18 Mar) | 26.4 | 10.8 | 18.6 | 89 | 39 | 64 | 0 | 27.4 | 8.8 |
| 12 (19-25 Mar) | 27.9 | 12.6 | 12.6 | 84 | 31 | 57 | 0 | 39.5 | 6.7 |
| 13 (26-01 Apr) | 31.8 | 15.3 | 23.5 | 84 | 34 | 59 | 0 | 34.8 | 7.6 |
| 14 (02-08 Apr) | 35.1 | 18.3 | 26.7 | 76 | 31 | 54 | 0 | 39.8 | 9.3 |
| 15 (09-15 Apr) | 32.1 | 17.7 | 24.9 | 76 | 37 | 56 | 19.8 | 41.6 | 7.9 |
| 16 (16-22 Apr) | 33.4 | 18.9 | 26.2 | 79 | 30 | 55 | 3.7 | 38.4 | 7.6 |
| 17 (23-29 Apr) | 34 | 17.6 | 25.8 | 68 | 31 | 50 | 15.1 | 42.4 | 9.4 |

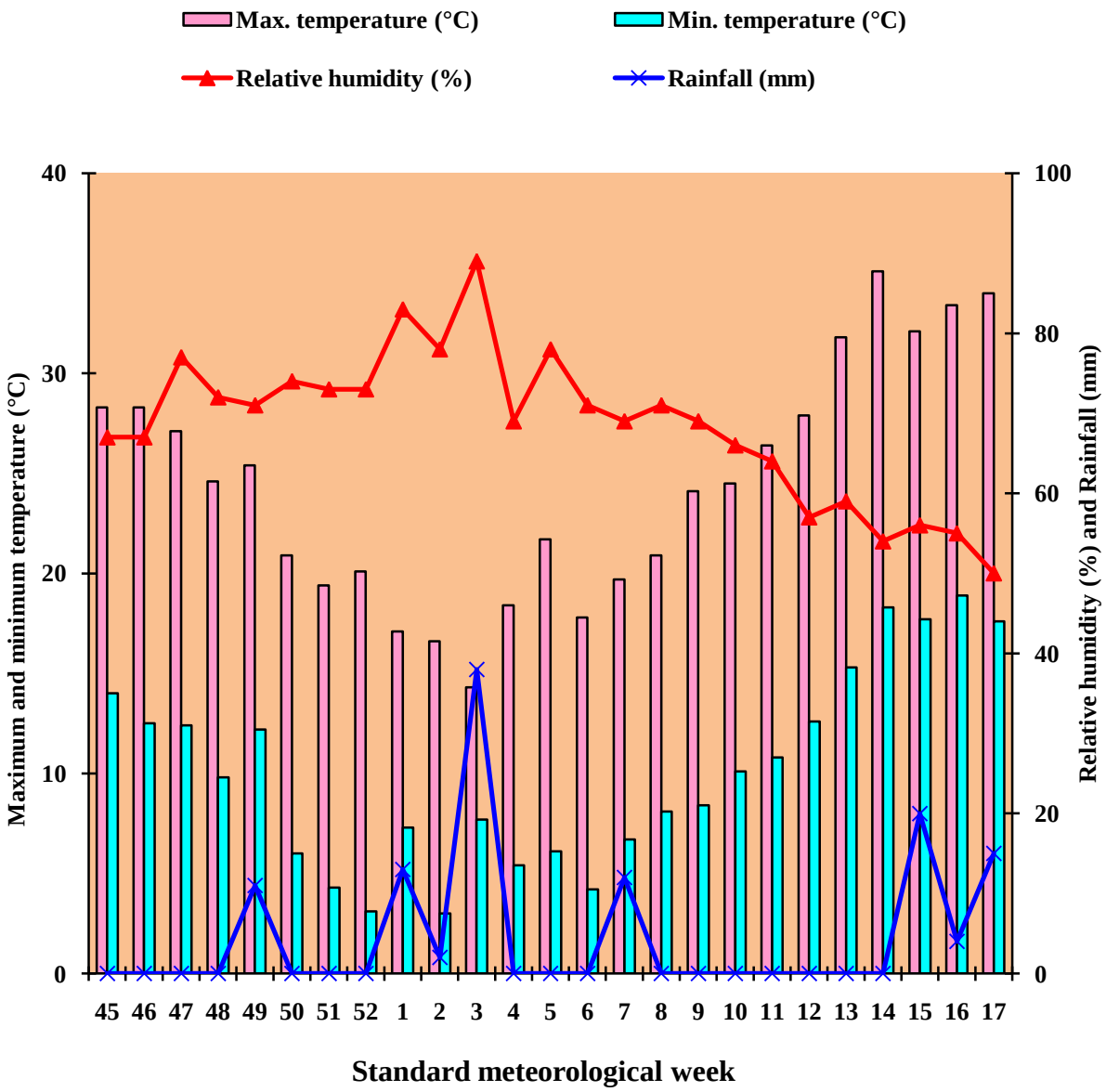



**Fig. 11 Standard weekly meteorological data recorded during crop season *rabi* 2011-12**

**Weekly standard meteorological data recorded during crop season *rabi* 2012-13**

| Standard Meteorological Week | Temperature (°C) | | | Relative Humidity (%) | | | Total Rainfall (mm) | Total Evaporation (mm) | SSH (hr) |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Mean | Morn. | Even. | Mean | | | |
| 45 (5-11 Nov.) | 28.7 | 12.3 | 20.5 | 91.1 | 39.4 | 65.2 | 0 | 1.9 | 5.4 |
| 46 (12-18 Nov.) | 26.2 | 10.5 | 18.3 | 95.0 | 44.7 | 69.8 | 0 | 1.6 | 6.1 |
| 47 (19-25 Nov.) | 25.2 | 9.0 | 17.1 | 89.5 | 35.8 | 62.6 | 0 | 2.0 | 6.9 |
| 48 (26-02 Dec.) | 23.7 | 7.4 | 15.5 | 89.5 | 39.4 | 64.4 | 0 | 2.2 | 8.1 |
| 49 (03-09 Dec.) | 24.0 | 5.9 | 14.9 | 90.8 | 36.5 | 63.6 | 0 | 2.0 | 8.1 |
| 50 (10-16 Dec.) | 20.0 | 10.8 | 15.4 | 90.8 | 70.7 | 80.7 | 2.4 | 1.3 | 4.4 |
| 51 (17-23 Dec.) | 19.4 | 8.1 | 13.7 | 93.5 | 59.5 | 76.5 | 0 | 1.7 | 7.6 |
| 52 (24-31 Dec.) | 13.8 | 7.3 | 10.5 | 92.0 | 74.0 | 83.0 | 0 | 1.1 | 0.6 |
| 1 (01-07 Jan) | 10.4 | 4.4 | 7.5 | 89.8 | 75.1 | 82.4 | 0 | 0.9 | 0.6 |
| 2 (08-14 Jan) | 18.6 | 4.6 | 11.6 | 92.4 | 62.7 | 77.5 | 0 | 1.3 | 6.9 |
| 3 (15-21 Jan) | 17.9 | 6.7 | 12.3 | 96.2 | 72.8 | 84.5 | 1.1 | 1.4 | 5.1 |
| 4 (22-28 Jan) | 19.5 | 4.2 | 11.8 | 97.4 | 49.5 | 73.4 | 0 | 1.9 | 8.3 |
| 5 (29-04 Feb) | 20.8 | 8.2 | 14.5 | 97.8 | 60.7 | 79.2 | 3.2 | 1.7 | 3.3 |
| 6 (05-11 Feb) | 19.8 | 7.4 | 13.6 | 98.8 | 66.4 | 82.6 | 0.1 | 2.1 | 8.6 |
| 7 (12-18 Feb) | 20.4 | 12.8 | 16.6 | 96.7 | 73.1 | 84.9 | 4.7 | 1.9 | 6.3 |
| 8 (19-25 Feb) | 20.0 | 11.1 | 15.5 | 98.5 | 73.7 | 86.1 | 5.0 | 2.0 | 5.3 |
| 9 (26-04 Mar) | 23.8 | 9.7 | 16.7 | 97.7 | 57.0 | 77.3 | 0.5 | 2.6 | 10.0 |
| 10 (05-11 Mar) | 28.7 | 12.9 | 20.8 | 93.8 | 50.4 | 72.1 | 0 | 3.5 | 9.4 |
| 11 (12-18 Mar) | 27.2 | 12.8 | 20.0 | 95.4 | 50.5 | 72.9 | 0.7 | 3.5 | 8.9 |
| 12 (19-25 Mar) | 28.7 | 14.6 | 21.6 | 95.1 | 47.8 | 71.4 | 4.1 | 4.3 | 9.6 |
| 13 (26-01 Apr) | 28.3 | 15.2 | 21.7 | 90.2 | 47.2 | 68.7 | 0.1 | 3.7 | 7.9 |
| 14 (02-08 Apr) | 32.0 | 15.2 | 23.6 | 80.7 | 25.2 | 52.9 | 0 | 6.5 | 11.1 |
| 15 (09-15 Apr) | 34.6 | 18.2 | 26.4 | 70.4 | 24.5 | 47.4 | 0 | 6.8 | 9.1 |
| 16 (16-22 Apr) | 35.7 | 19.2 | 27.4 | 50.1 | 17.5 | 33.8 | 0 | 8.0 | 9.8 |
| 17 (23-29 Apr) | 34.4 | 20.3 | 27.3 | 57.2 | 28.8 | 43.0 | 0.6 | 5.6 | 6.3 |

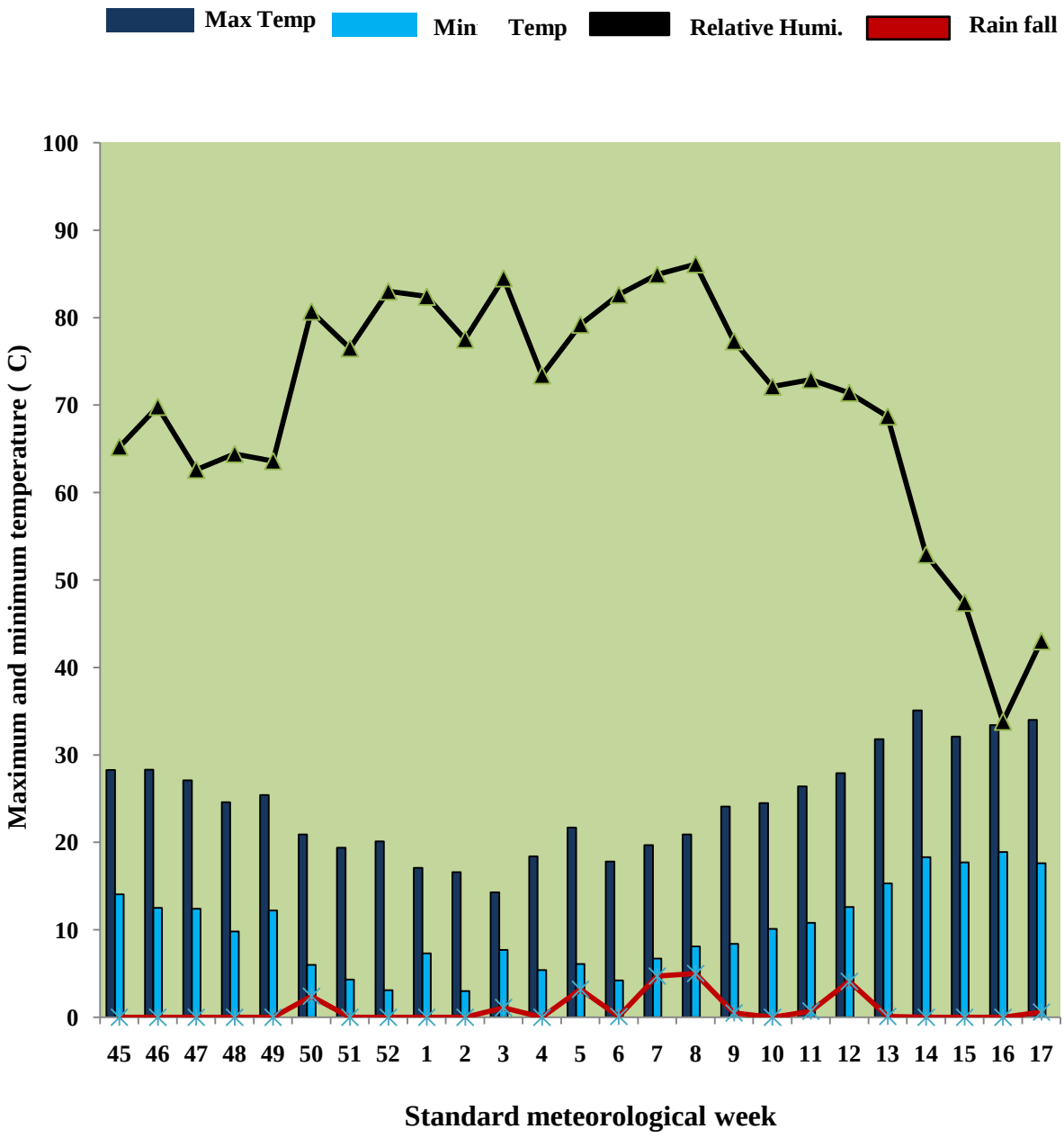
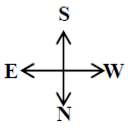


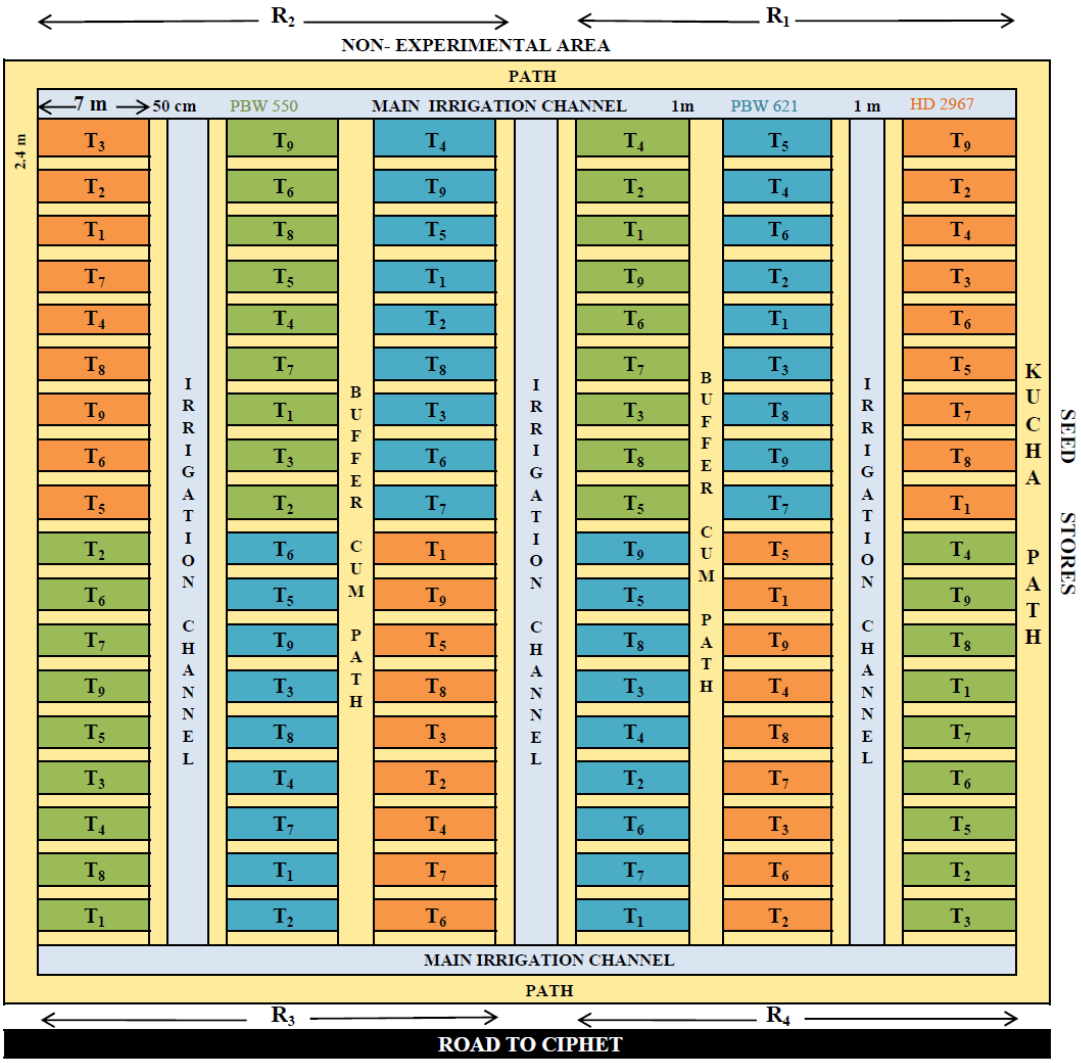

**Fig. 12 Standard weekly meteorological data recorded during crop season *rabi* 2012-13**

ANNEXURE XII

## LAY-OUT PLAN OF EXPERIMENT NO. 1

**Impact of nitrogen, zinc and iron on growth, productivity, agronomic biofortification and quality of wheat.**




$T_1$ = Recommended dose of NPK (Control)

$T_2$ = $T_1$ + $ZnSO_4.7H_2O$ @ 62.5 kg/ha (soil application)

$T_3$ = $T_1$ + three foliar sprays of 0.5 % $ZnSO_4.7H_2O$

$T_4$ = $T_2$ + three foliar sprays of 0.5 % $ZnSO_4.7H_2O$

$T_5$ = $T_1$ + three foliar sprays of 0.5 % $FeSO_4$. $7H_2O$ at mid-boot, pre milk and dough stage

$T_6$ = $T_1$ + $ZnSO_4.7H_2O$ @ 62.5 kg/ha (soil application) + N 50 kg/ha 80 DAS

$T_7$ = $T_1$ + N @ 50 kg/ha at 80 DAS + three foliar sprays of 0.5 % $ZnSO_4.7H_2O$ at mid-boot, pre milk and dough stage

$T_8$ = $T_1$ + soil application $ZnSO_4.7H_2O$ @ 62.5 kg/ha + N @ 50 kg/ha 80 DAS + three foliar sprays of lime neutralized 0.5 % $ZnSO_4.7H_2O$ at pre (mid-boot stage) and post-anthesis (pre-milk and dough stage)

$T_9$ = $T_1$ + N @ 50 kg/ha at 80 DAS + three foliar sprays of $FeSO_4$. $7H_2O$ (0.5 %) at mid-boot, pre milk and dough stage

**Soil Status**

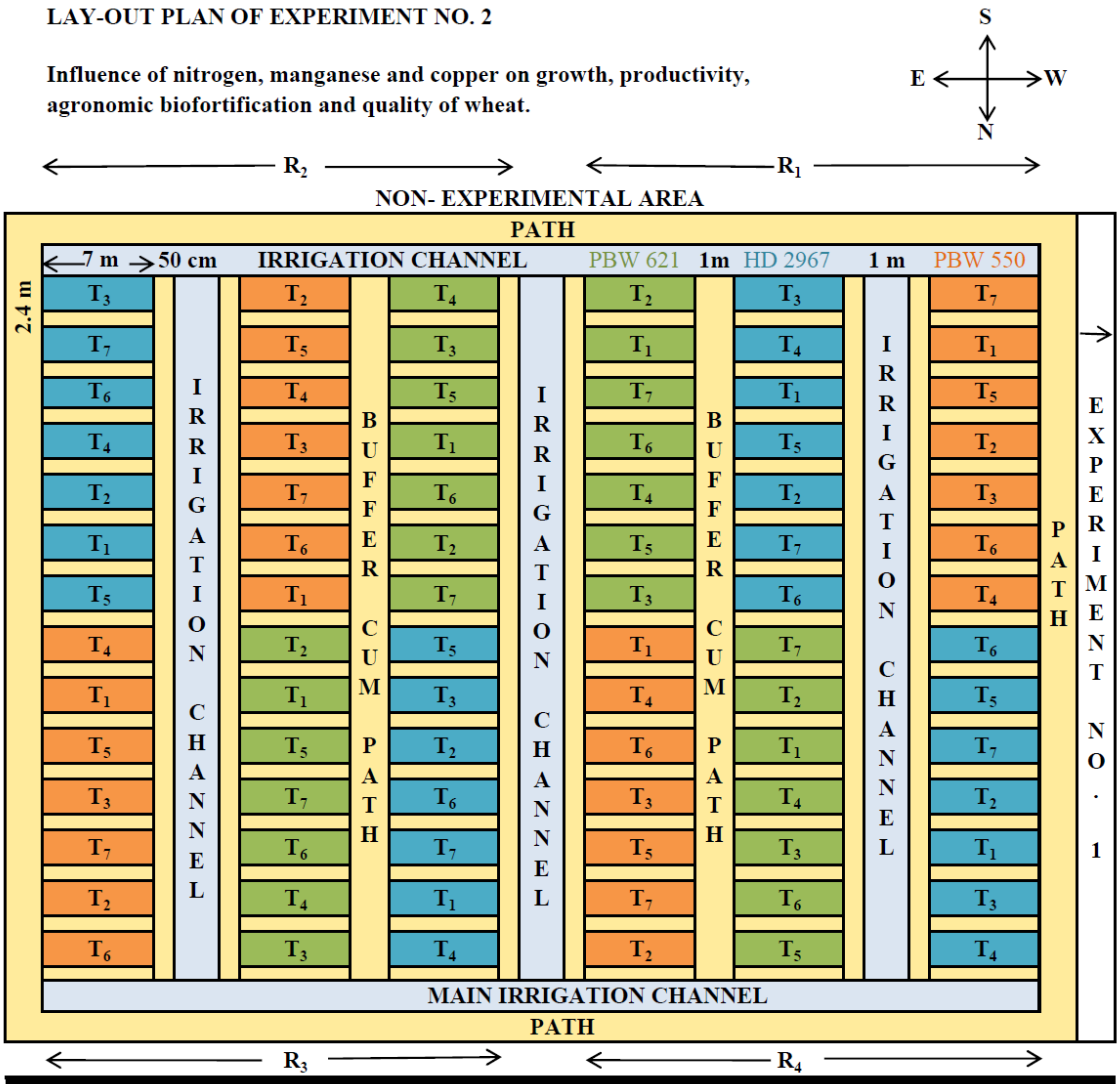
loamy sand soil, testing near normal in pH, low EC, low in available N, medium in available P and K, medium in available Zn and low in Fe.

DTPA extractable Zn in soil was 0.62 mg/kg i.e. just above the critical level (0.60 mg/kg)

DTPA extractable Fe in soil was 3.49 mg/kg i.e. below the critical level (4.50 mg/kg)

**LAY-OUT PLAN OF EXPERIMENT NO. 2**

**Influence of nitrogen, manganese and copper on growth, productivity, agronomic biofortification and quality of wheat.**




**Treatments**

**A) Varieties (3) : Main Plot**

**(i) PBW 550 (II) PBW 621 (III) HD 2967**

**B) Nutrient applications (7): Sub-plot**

**$T_1$ = Recommended dose of NPK (Control)**

**$T_2$ = $T_1$ + three foliar sprays of 0.5 % $MnSO_4$. $H_2O$ during pre (mid boot) and post-anthesis (pre-milk and dough stage).**

**$T_3$ = $T_1$ + three foliar sprays of lime neutralised 0.1 % $CuSO_4$ $5H_2O$ during mid boot, pre-milk and dough stages.**

**$T_4$ = $T_1$ + three foliar sprays of 0.5 % $MnSO_4$ $H_2O$ and three foliar sprays of lime neutralised 0.1 % $CuSO_4$. $5H_2O$ during mid boot, pre milk and dough stages.**

**$T_5$ = $T_1$ + N @ 50 Kg/ha 80 DAS + three foliar sprays of 0.5 % $MnSO_4$ $H_2O$ during mid boot, pre milk and dough stages.**

**$T_6$ = $T_1$ + N @ 50 kg/ha 80 DAS three foliar sprays of lime neutralised 0.1 % $CuSO_4$ $5H_2O$ during mid boot, pre-milk and dough stages.**

**$T_7$ = $T_1$ + N @ 50 kg/ha at 80 DAS + three foliar sprays of 0.5 % $MnSO_4$ $H_2O$ + three foliar sprays of lime neutralised 0.1 % $CuSO_4$ $5H_2O$ during mid boot, pre-milk and dough stages.**

**Soil Status**

**loamy sand soil testing near normal in pH, low EC, low in O C, low in available N, medium in available P and K, low in available Cu and Mn.**

**DTPA extractable Mn in soil was 3.40 µg/g i.e. lower than the critical level (3.50 mg/kg)**
**DTPA extractable Cu in soil was 0.18 µg/g i.e. lower than the critical level (0.20 mg/kg)**

## ANNEXURE XIII

### GENERAL METHODOLOGY

**Location of experimental site**

The field experiment entitled, **"Agronomic biofortification and enhancement of productivity in bread wheat (*Triticum aestivum*) varieties"** was conducted at the Research Farm of Department of Agronomy, Punjab Agricultural University, Ludhiana during ***rabi*** 2011-12 and 2012-13 representing the Indo-Gangetic alluvial plains, situated at $30^0$ 56/ N latitude and $75^0$ 52/ E longitude and at an altitude of 247 meters above mean sea level.

**Weather and climate**

The area is characterized by sub-tropical and semi-arid type of climate with hot and dry early summer from April to June followed by hot and humid period during July-September and cold winters during November to January. The mean maximum and minimum temperature show significant ups and downs during various months of the year. Summer temperature crosses $38^0$C and touches $47^0$C with dry summer spells. Winter experiences frequent frosty spells especially in December and January and minimum temperature records low up to $0.5^0$C. The annual rainfall of the area is 735 mm, most of which is received during July to September.

The meteorological data for the experimental season were recorded from meteorological observatory of the Punjab Agricultural University, Ludhiana. The meteorological data during wheat growing season have indicated that the total amount of rainfall received during crop season *Rabi* 2011-12 was 107.2 mm. Mean maximum and minimum air temperature was recorded to be $24.5^0$ C and $10.2^0$ C respectively. The mean relative humidity during crop season was recorded to be 66 %. The total amount of rainfall received during crop season *Rabi* 2012-13 was 22.5 mm. Mean maximum and minimum air temperature was recorded to be $24.07^0$ C and $10.76^0$ C respectively. The mean relative humidity during crop season was recorded to be 70% (Annexure XI, Fig 11 and Fig 12).

**Field layout**

The crop was sown in two trials each consisting of three bread wheat varieties viz. PBW 621, PBW 650 and HD 2967 in split design with 4 replications with a plot size of 7m x 2.4 m and 12 rows per plot during the cropping seasons of *rabi* 2011-12 and 2012-13. The experiment I was laid out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with seven nutrient management treatments ($T_1$: NPK alone as control, $T_2$: NPK+Mn (f), $T_3$: NPK+Cu (f), $T_4$: NPK+Mn (f)+Cu (f), $T_5$: NPK+$N_{50}$+Mn

(f), $T_6$: NPK+$N_{50}$+Cu (f) and $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) in the sub plots. The experiment II was also laid-out in split-plot design with three bread wheat varieties viz. HD 2967, PBW 621 and PBW 550 in main plot in combination with nine nutrient treatments $T_1$: NPK (Control), $T_2$: NPK+Zn (s), $T_3$: NPK+Zn (f), $T_4$: NPK+Zn (s)+Zn (f), $T_5$: NPK+Fe (f), $T_6$: NPK+Zn (s)+$N_{50}$, $T_7$: NPK+$N_{50}$+Zn (f), $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) and $T_9$: NPK+$N_{50}$+Fe (f) in the sub-plots.

**Experiment I:**

**Name of the experiment: Influence of nitrogen, zinc and iron on growth, productivity, agronomic biofortification and quality of wheat.**

| | | |
|---|---|---|
| Number of treatments | : | 27 |
| Number of replications | : | 4 |
| Number of plots | : | 108 |
| Design | : | Split-plot design |

**Experiment II:**

**Name of the experiment: Influence of nitrogen, manganese and copper on growth, productivity, agronomic biofortification and quality of wheat.**

| | | |
|---|---|---|
| Number of treatments | : | 21 |
| Number of plots | : | 84 |
| Number of replications | : | 4 |
| Design | : | Split-plot design |
| Row spacing | = | 20 cm |
| Seed rate | = | 100 kg/ha (for PBW 621 and HD 2687)<br>112.5 kg/ha (for PBW 550) |
| No of rows sown/plot | = | 12 |
| Rows harvested/plot | = | 8 |
| Gross plot size | = | 7 m x 2.4 m = 16.8 $m^2$ |
| Net plot harvested | = | 6 m x 1.60 m = 9.60 $m^2$ |
| Date of harvesting | = | April 25, 2011and 2012 |
| Fertilizer source | | Urea (46 % N), DAP (18 % N, 46 % $P_2O_5$), MOP (60 % $K_2O$), $ZnSO_4.7H_2O$ (21 %) used for soil application and $CuSO_4.5H_2O$ (25 %), $MnSO_4.H_2O$ (26 %), $FeSO_4.7H_2O$ (19 %) of LR grade were used for foliar sprays. |

**Agronomic practices**

The details of agronomic practices followed for crop raised during ***rabi*** **season 2011-12** and **2012-13** are given below:

**Field preparation**

After giving primary tillage, heavy pre-sowing irrigation was applied on November 2. On November 4, the field was prepared twice with cultivator followed by planking to prepare a fine seedbed.

**Sowing**

The sowing was done with *kera* method in the 6-7 November 2011 and 2012. Seeds were sown at 5 cm depth and at a row to row spacing of 20 cm. Seed rate for variety PBW 550 was 112.5 kg/ha whereas for varieties HD 2967 and PBW 621 was 100 kg/ha.

**Fertilizer application**

Nitrogen (N) was applied @125 kg/ha as urea in 3 splits (1/2 at sowing, 1/4 with first irrigation and 1/4 with second irrigation). Additional dose of N @ 50 kg/ha was applied by top-dressing before heading stage at 80 DAS. Phosphorus ($P_2O_5$) @62.5 kg/ha as DAP ($P_2O_5$-18 %, N- 46 %) and Potassium ($K_2O$) @30 kg/ha in the form of muriate of Potash ($K_2O$-60 %) fertilizers were applied with at the time of sowing. Soil application of $ZnSO_4$ (21 %) was done @ 62.5 kg/ha. Three Foliar sprays each of $ZnSO_4$ (0.5 %), $FeSO_4$ (0.5 %), $MnSO_4$ (0.5 %) and $CuSO_4$ (0.1 %) were done at mid-booting, pre-milking and dough stages of wheat.

**Herbicide application**

To control broad leaf weeds, Algrip (metsulfuron) @ 25 g/ha as commercial product and to control grass weeds, Topic (Clodinofop) herbicide @ 400 g/ha were applied 35 DAS.

**Fungicide application**

Two foliar sprays of Tilt (Propiconazole) 25 EC @ 500 ml/ha was done at weekly interval to control yellow rust during milk stage of grain ripening of wheat crop.

**Irrigations**

During the year 2011-12, the post-sowing six irrigations were applied on 30 November, 2011; 25 December, 2011; 25 January, 2011; 15 February, 2012; 10 March, 2012 and 31 March, 2012. During the year 2012-13, the post-sowing six irrigations were applied on 23 November, 2012; 18 December, 2012; 18 January, 2013; 8 February , 2013; 3 March , 2013 and 24 March, 2013. Each irrigation was of 7.5 cm depth.

**Harvesting & Threshing**

The crop was harvested manually on 25 April 2012 and 2013. After sun drying in open for three days, threshing was carried out with engine operated thresher. Grain weight was

recorded after cleaning the produce.

**Soil Analysis**

From the experimental field, representative soil samples were collected before sowing at a soil depth of 0-15cm and 15-30 cm, air-dried, ground and sieved for chemical analysis. The results of soil test are given in table no.1. The soil of the experimental field was loamy-sand in texture with low electrical conductivity and suitable for crop growth. The chemical analysis of the soil revealed that soil is low in available nitrogen, iron, copper and manganese and medium in phosphorus, potassium and zinc.

**Table 1: Chemical properties of the soil of experimental field (before sowing)**

| **Characters** | **0-15** | **15-30** | **Rating** | **Method used** |
|---|---|---|---|---|
| pH | 7.30 | 7.65 | Near normal | Beckman's glass electronic pH meter in 1:2 soil : water suspension (Jackson 1973) |
| EC (dS/m) | 0.15 | 0.13 | Low | 1:2 soil : water supernatant Solubridge conductivity meter (Jackson 1967) |
| Organic carbon (%) | 0.24 | 0.15 | Low | Walkley and Black's rapid titration method (Jackson 1967) |
| Available N (kg/ha) | 180.2 | 173.8 | Low | Modified alkaline potassium permanganate method (Subbiah and Asija 1956) |
| Available P (kg/ha) | 12.5 | 12.4 | Medium | 0.5 N sodium bicarbonate extractable P by Olsen's method (Olsen *et al* 1954) |
| Available K (kg/ha) | 142.6 | 139.8 | Medium | Ammonium acetate extractable K (Jackson 1967) |
| Available zinc (µg/g) | 0.62 | 0.40 | medium | Atomic Absorption Spectrophotometer (Varian-AAS FS 240 Model) |
| Available iron (µg/g) | 3.49 | 3.32 | Low | AAS |
| Available copper (µg/g) | 0.18 | 0.16 | Low | AAS |
| Available manganese (µg/g) | 3.40 | 3.30 | Low | AAS |

The results presented in Table 1 and 2 categorize the soil of experimental field as loamy-sand with near normal reaction, low in organic carbon and available nitrogen and medium in

available phosphorus and potassium and low in DTPA extractable microelements such as Zn, Fe, Mn and Cu.

**Table 2: Mechanical characteristics of the soil of experimental site**

| **chracter** | **Soil depth (cm)** | | **Method used** |
|---|---|---|---|
| | 0-15 | 15-30 | International pippet method (Piper 1966) |
| **Sand (%)** | 82.30 | 81.70 | |
| **Silt (%)** | 7.2 | 6.7 | |
| **Clay (%)** | 10.5 | 11.6 | |
| **Textural class** | Loamy sand | Loamy sand | |

**PHYSICAL CHARACTERS**

The soil samples were collected layer wise from three different spots viz. 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm depth in experimental field. The samples of the respective depths were composited to determine the physical soil moisture constants. The field capacity and permanent wilting point of 0-180 cm rhizosphere were 36.56 cm and 11.55 cm respectively. Hence, the available water in the 0-180 cm of soil profile comes out to be 25.01 cm. The average bulk density of the soil was 1.58 g/cm$^3$ (Table 3).

**Table 3: Physical characteristics of soil profile of the experimental site**

| **Soil Depth (cm)** | **Field capacity moisture (cm)** | **Permanent wilting point moisture (cm)** | **Bulk density (g/cm$^3$)** |
|---|---|---|---|
| 0-15 | 2.60 | 0.88 | 1.70 |
| 15-30 | 2.80 | 0.80 | 1.67 |
| 30-60 | 4.90 | 1.70 | 1.62 |
| 60-90 | 6.45 | 1.98 | 1.61 |
| 90-120 | 6.50 | 2.06 | 1.55 |
| 120-150 | 6.60 | 2.08 | 1.50 |
| 150-180 | 6.71 | 2.05 | 1.48 |
| Total | 36.56 | 11.55 | Average = 1.58 |
| Method used | Pressure plate apparatus (Richards and Weaver 1943) | Pressure plate apparatus (Richards and Weaver 1943) | Core Sampler Method (Bobman 1942) |

**Determination of β-Carotene pigment (ppm)**

Water saturated butanol was used to extract the β-carotene pigment. Butyl alcohol was saturated with water in a glass separator funnel. About 100 ml of distilled water was added followed by 150 ml of butanol. The mixture of these two solutions was agitated in separator funnel and after formation of two visible layers, the lower layer was drained and remaining butanol was stored and further used as saturated butanol. 4 grams of ground flour sample was taken in 100 ml bottle with air-tight stopper to which about 20 ml of water saturated butanol was added. The contents were mixed and kept overnight in the dark mixed again before filtration. Absorbance of the filtrate was measured at 440 nm using UV-VIS spectrophotometer using water saturated butanol as blank. β-Carotene content was calculated as follows:

β-Carotene (ppm)=0.0105+23.5366 x Optical Density (O.D.)

**Soil analysis:**

Soil samples (10g each) were chemically analyzed for N, P, K, Zn, Fe Cu and Mn according to procedures given as follows:

Nitrogen was determined by the procedures given by Subbiah and Asija (1956) through Kjeldehl method. Soil Zn, Fe, Mn and Cu were determined with method of diethylene triamine pentaacetic acid (DTPA) (Lindsay and Norvell 1978).

**Plant analysis**

The grain and straw samples from each plot were taken to estimate N, P, K, Zn, Fe, Mn and Cu content. To determine N content a sample of 0.5g of straw/grain was digested in conc. $H_2SO_4$ and digestion mixture (selenium dioxide + copper sulphate + potassium sulphate) to determine total nitrogen content. The nitrogen content of straw and grains was determined by modified Kjeldahl's method (Piper 1966).

Plant samples were dried at $60^0$C in a hot air oven for 48 hours and ground in a hot air oven for 48 hours and ground in a stainless steel Wiley mill through a 60 mesh size. Known aliquot (0.5 and 1 g of straw and grain resp.) were transferred in to digestion tubes treated with 5 ml of conc. Distilled $HNO_3$ and kept overnight. The digestion was done in a block digestion unit at $125^0$C for 2 hours till 2 ml of acid was left. The contents of the digestion tubes were diluted with de-ionised water to make a volume of 10 ml and transferred to analytical tubes for settling of the insoluble material. The supernatant was analyzed. The soil and plant extract were analyzed for the simultaneous determination of different micronutrients on AAS.

**Nutrient uptake**

The nitrogen content (%) determined with modified Kjeldahl's method (Piper 1966) was directly multiplied with total grain yield (kg/ha) to determine nitrogen uptake by grains. The nitrogen in straw was determined by wet digestion method and then multiplied with total straw yield. The two combined figures give the total nitrogen uptake by plant on Kg/ha basis. Zn, Fe, Mn and Cu uptake (g/ha) was determined by multiplying their percent nutrient concentration (µg/g) with their respective yields (kg/ha) divided by 10.

**Statistical analysis**

The data regarding present investigations were statistically analyzed as per the standard procedure prescribed by Cochran and Cox (1967) and adopted by Cheema and Singh (1991) in statistical package CPCS-I for split-plot design The comparisons were made at 5 per cent level of significance. The experiment wise split-up of degree of freedom in the analysis of variance was as follows :

**Table 4. Split-up degree of freedom for experiment I**

| **Source of variation** | **df** | **Degree of freedom (df)** |
|---|---|---|
| Replications (r) | (r-1) | 3 |
| Varieties (A) | (a-1) | 2 |
| Error (a) | (r-1) (a-1) | 6 |
| Nutrient applications (B) | (b-1) | 8 |
| varieties × Nutrient applications | (a-1)(b-1) | 16 |
| Error (b) | a(r-1)(b-1) | 72 |
| Total | rab-1 | 107 |

**Table 5. Split-up degree of freedom for experiment II**

| Source of variation | df | Degree of freedom (df) |
|---|---|---|
| Replications (r) | (r-1) | 3 |
| Varieties (A) | (a-1) | 2 |
| Error (a) | (r-1) (a-1) | 6 |
| Nutrient applications (B) | (b-1) | 6 |
| Varieties × Nutrient applications | (a-1)(b-1) | 12 |
| Error (b) | a(r-1)(b-1) | 54 |
| Total | rab-1 | 83 |

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**ANNEXURE XIV**

**Experiment 1**

**Impact of N, Zn and Fe on growth, productivity, agronomic biofortification and quality of wheat.**

**Table 1. Effect of wheat varieties and nutrient management on crop emergence**

| Treatment | Emergence count/$m^2$ | |
|---|---|---|
| | **2011-12** | **2012-13** |
| **Varieties (V)** | | |
| $V_1$: HD 2967 | 203 | 199 |
| $V_2$: PBW 621 | 205 | 198 |
| $V_3$: PBW 550 | 201 | 192 |
| **LSD (p=0.05)** | **NS** | **NS** |
| **Nutrient management (N)** | | |
| $T_1$: NPK (Control) | 199 | 196 |
| $T_2$: NPK+*Zn (s) | 200 | 197 |
| $T_3$: NPK+**Zn (f) | 200 | 197 |
| $T_4$: NPK+Zn (s)+Zn (f) | 201 | 197 |
| $T_5$: NPK+**Fe (f) | 201 | 198 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 200 | 197 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 201 | 198 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 202 | 198 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 201 | 198 |
| **LSD (p=0.05) : N** | **NS** | **NS** |
| **V x N** | **NS** | **NS** |

*** Soil application of $ZnSO_4.7H_2O$ (21%) @ 62.5 Kg/ha before sowing**

***Foliar spray of 0.5% $FeSO_4.7H_2O$ and $ZnSO_4.7H_2O$ separately done at mid-boot, pre-milk and dough stages**

*****N @ 50 Kg/ha applied as top dressing at 80 DAS**

**DTPA extractable Zn in soil was 0.62 mg/kg i.e. just above the critical level (0.60 mg/kg)**

**DTPA extractable Fe in soil was 3.49 mg/kg i.e. below the critical level (4.50 mg/kg)**

**Table 2. Periodic plant height as affected by wheat varieties and nutrient management**

| Treatment | Plant height (cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 DAS | | 90 DAS | | 120 DAS | | At harvest | |
| | 11-12 | 12-13 | 11-12 | 12-13 | 11-12 | 12-13 | 11-12 | 12-13 |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 27.9 | 24.4 | 48.1 | 46.9 | 86.7 | 84.3 | 94.6 | 90.4 |
| $V_2$: PBW 621 | 28.7 | 25.5 | 50.6 | 48.2 | 88.9 | 85.1 | 93.8 | 90.1 |
| $V_3$: PBW 550 | 30.6 | 26.7 | 72.3 | 69.5 | 79.8 | 75.6 | 82.5 | 80.1 |
| **LSD (p=0.05)** | **NS** | **NS** | **6.4** | **5.5** | **6.2** | **5.2** | **5.9** | **7.4** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 29.1 | 25.3 | 48.2 | 46.3 | 76.4 | 73.1 | 82.1 | 77.8 |
| $T_2$: NPK+*Zn (s) | 29.7 | 25.9 | 56.3 | 53.5 | 84.1 | 80.3 | 89.3 | 87.2 |
| $T_3$: NPK+**Zn (f) | 28.9 | 24.6 | 58.0 | 56.0 | 86.5 | 82.7 | 92.7 | 89.7 |
| $T_4$: NPK+Zn (s)+Zn (f) | 29.9 | 24.8 | 61.3 | 59.3 | 89.4 | 86.1 | 95.0 | 88.9 |
| $T_5$: NPK+**Fe (f) | 29.1 | 25.5 | 51.0 | 48.9 | 79.1 | 75.6 | 84.6 | 80.7 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 30.0 | 26.4 | 58.8 | 56.6 | 86.9 | 83.4 | 92.4 | 88.3 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 29.0 | 25.3 | 61.0 | 58.8 | 89.5 | 85.7 | 94.6 | 91.6 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 30.1 | 27.2 | 62.8 | 61.0 | 90.9 | 87.7 | 96.7 | 92.4 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 29.2 | 25.1 | 55.7 | 53.4 | 83.8 | 80.2 | 89.1 | 86.3 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **3.4** | **2.6** | **2.3** | **1.8** | **1.9** | **2.4** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

**Table 3. Periodic dry matter accumulation as influenced by wheat varieties and nutrient management**

| Treatment | Dry matter accumulation (q/ha) | | | | | |
|---|---|---|---|---|---|---|
| | 60 DAS | | 90 DAS | | 120 DAS | |
| | 11-12 | 12-13 | 11-12 | 12-13 | 11-12 | 12-13 |
| **Varieties (V)** | | | | | | |
| $V_1$: HD 2967 | 26.1 | 23.5 | 36.7 | 33.1 | 120.4 | 115.1 |
| $V_2$: PBW 621 | 27.9 | 25.2 | 45.6 | 42.2 | 122.8 | 117.2 |
| $V_3$: PBW 550 | 28.5 | 26.6 | 62.2 | 57.4 | 115.6 | 108.4 |
| **LSD (p=0.05)** | **NS** | **NS** | **6.8** | **6.5** | **5.5** | **7.0** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK (Control) | 26.9 | 24.4 | 39.8 | 36.5 | 94.2 | 92.3 |
| $T_2$: NPK+*Zn (s) | 28.2 | 25.5 | 40.7 | 41.1 | 118.2 | 110.2 |
| $T_3$: NPK+**Zn (f) | 27.3 | 24.7 | 40.2 | 38.5 | 122.3 | 114.9 |
| $T_4$: NPK+Zn (s)+Zn (f) | 28.0 | 25.6 | 50.1 | 48.3 | 123.8 | 125.1 |
| $T_5$: NPK+**Fe (f) | 27.3 | 24.7 | 32.7 | 29.6 | 114.2 | 102.4 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 28.4 | 25.6 | 41.8 | 38.7 | 120.4 | 117.3 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 27.5 | 24.8 | 46.4 | 43.2 | 124.2 | 123.2 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 28.2 | 25.7 | 55.7 | 52.6 | 136.8 | 131.3 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 27.6 | 24.8 | 30.6 | 27.5 | 119.1 | 109.4 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **2.4** | **3.1** | **3.4** | **5.4** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

**Table 4. Leaf area index (LAI) at different phenological stages as influenced by wheat varieties and nutrient management**

| Treatment | Leaf area Index | | | | | |
|---|---|---|---|---|---|---|
| | 60 DAS | | 90 DAS | | 120 DAS | |
| | 11-12 | 12-13 | 11-12 | 12-13 | 11-12 | 12-13 |
| **Varieties (V)** | | | | | | |
| $V_1$: HD 2967 | 2.65 | 2.60 | 4.77 | 4.72 | 3.85 | 3.79 |
| $V_2$: PBW 621 | 2.66 | 2.62 | 4.89 | 4.85 | 3.97 | 3.92 |
| $V_3$: PBW 550 | 2.72 | 2.70 | 4.63 | 4.60 | 3.64 | 3.59 |
| **LSD (p=0.05)** | **NS** | **NS** | **0.07** | **0.06** | **0.09** | **0.08** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK (Control) | 2.70 | 2.68 | 4.16 | 4.10 | 3.00 | 2.97 |
| $T_2$: NPK+*Zn (s) | 2.75 | 2.71 | 4.28 | 4.24 | 3.22 | 3.19 |
| $T_3$: NPK+**Zn (f) | 2.71 | 2.70 | 4.32 | 4.26 | 3.30 | 3.27 |
| $T_4$: NPK+Zn (s)+Zn (f) | 2.76 | 2.74 | 4.90 | 4.86 | 3.92 | 3.89 |
| $T_5$: NPK+**Fe (f) | 2.73 | 2.71 | 4.20 | 4.16 | 3.10 | 3.07 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 2.77 | 2.73 | 4.45 | 4.41 | 3.70 | 3.65 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 2.72 | 2.69 | 4.76 | 4.72 | 3.83 | 3.80 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 2.74 | 2.72 | 5.25 | 5.21 | 4.37 | 4.32 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 2.71 | 2.68 | 4.24 | 4.20 | 3.16 | 3.13 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **0.11** | **0.07** | **0.1** | **0.09** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 5. Periodic tiller count as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Tillers/m$^2$** | | | | | | | |
| | **60 DAS** | | **90 DAS** | | **120 DAS** | | **At harvest** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 328 | 324 | 356 | 347 | 339 | 326 | 328 | 324 |
| $V_2$: PBW 621 | 334 | 329 | 361 | 352 | 342 | 328 | 336 | 333 |
| $V_3$: PBW 550 | 325 | 319 | 340 | 330 | 333 | 321 | 321 | 317 |
| **LSD (p=0.05)** | **6** | **5** | **7** | **6** | **3** | **2** | **5** | **3** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 327 | 320 | 350 | 346 | 314 | 312 | 292 | 289 |
| $T_2$: NPK+*Zn (s) | 332 | 324 | 370 | 363 | 340 | 337 | 327 | 321 |
| $T_3$: NPK+**Zn (f) | 328 | 319 | 379 | 376 | 350 | 344 | 336 | 334 |
| $T_4$: NPK+Zn (s)+Zn (f) | 331 | 325 | 395 | 384 | 380 | 375 | 376 | 371 |
| $T_5$: NPK+**Fe (f) | 327 | 322 | 361 | 354 | 328 | 322 | 312 | 308 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 333 | 324 | 377 | 371 | 360 | 354 | 350 | 347 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 328 | 321 | 386 | 382 | 375 | 371 | 371 | 365 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 332 | 325 | 401 | 397 | 394 | 390 | 389 | 384 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 329 | 322 | 365 | 359 | 345 | 338 | 334 | 329 |
| **LSD (p=0.05) : N** | **3** | **3** | **8** | **7** | **7** | **6** | **6** | **4** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 6. Yield attributes as influenced by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Effective tillers/$m^2$** | | **Ear length (cm)** | | **Grains/ear** | | **1000-grain wt (g)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 325 | 321 | 10.1 | 9.8 | 39.4 | 38.1 | 42.1 | 40.8 |
| $V_2$: PBW 621 | 329 | 326 | 10.3 | 10.1 | 42.0 | 40.5 | 42.9 | 41.2 |
| $V_3$: PBW 550 | 315 | 309 | 10.8 | 10.7 | 45.6 | 44.2 | 45.5 | 44.0 |
| **LSD (p=0.05)** | **10** | **12** | **0.2** | **0.3** | **0.3** | **0.2** | **NS** | **NS** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 288 | 277 | 9.4 | 9.3 | 39.9 | 39 | 38.4 | 37.2 |
| $T_2$: NPK+*Zn (s) | 310 | 308 | 10.0 | 9.8 | 40.9 | 40.5 | 42.9 | 38.9 |
| $T_3$: NPK+**Zn (f) | 329 | 324 | 10.3 | 10.1 | 41.7 | 40.6 | 43.2 | 41.6 |
| $T_4$: NPK+Zn (s)+Zn (f) | 370 | 366 | 11.2 | 10.7 | 44.1 | 42.8 | 46.6 | 45.0 |
| $T_5$: NPK+**Fe (f) | 302 | 300 | 10.1 | 9.7 | 41.3 | 39.2 | 40.4 | 41.3 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 347 | 342 | 10.3 | 10.4 | 42.9 | 41.0 | 44.4 | 43.5 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 366 | 361 | 10.8 | 10.7 | 43.0 | 41.8 | 45.6 | 43.9 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 386 | 382 | 11.2 | 11.0 | 44.9 | 43.3 | 47.7 | 44.2 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 327 | 322 | 10.3 | 9.9 | 41.8 | 40.2 | 42.3 | 42.4 |
| **LSD (p=0.05) : N** | **13** | **15** | **0.5** | **0.4** | **0.8** | **0.9** | **1.3** | **1.1** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 7. Yield and harvest index as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Grain yield (q/ha)** | | **Straw yield (q/ha)** | | **Biological yield (q/ha)** | | **Harvest Index (HI)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 45.60 | 44.42 | 73.31 | 69.51 | 118.91 | 113.93 | 38.35 | 38.99 |
| $V_2$: PBW 621 | 47.41 | 48.95 | 74.37 | 67.23 | 121.80 | 116.18 | 38.92 | 42.13 |
| $V_3$: PBW 550 | 51.34 | 48.47 | 63.19 | 58.85 | 114.50 | 107.32 | 44.83 | 45.16 |
| **LSD (p=0.05)** | **5.35** | **3.61** | **2.4** | **3.24** | **NS** | **NS** | **0.34** | **0.36** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 36.11 | 33.07 | 64.46 | 55.41 | 100.57 | 88.48 | 35.90 | 37.38 |
| $T_2$: NPK+*Zn (s) | 47.96 | 45.66 | 68.47 | 63.42 | 116.43 | 109.08 | 41.19 | 41.86 |
| $T_3$: NPK+**Zn (f) | 49.99 | 47.81 | 70.24 | 66.02 | 120.23 | 113.82 | 41.50 | 42.00 |
| $T_4$: NPK+Zn (s)+Zn (f) | 51.76 | 53.85 | 70.03 | 69.94 | 121.79 | 123.8 | 42.50 | 43.50 |
| $T_5$: NPK+**Fe (f) | 43.83 | 41.68 | 68.22 | 59.65 | 112.05 | 101.33 | 39.12 | 41.13 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 49.56 | 49.47 | 70.72 | 66.43 | 120.28 | 115.9 | 41.23 | 42.68 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 51.13 | 52.58 | 70.97 | 69.45 | 122.10 | 122.03 | 41.88 | 43.09 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 55.85 | 56.53 | 78.97 | 72.93 | 134.82 | 129.47 | 41.43 | 43.66 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 46.83 | 44.83 | 70.55 | 63.52 | 117.38 | 108.35 | 39.90 | 41.38 |
| **LSD (p=0.05) : N** | **4.33** | **3.56** | **5.18** | **6.4** | **13.68** | **10.63** | **0.52** | **0.68** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 8. Effect of wheat varieties and nutrient management on grain yield (q/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **HD 2967** | | **PBW 621** | | **PBW 550** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| $T_1$: NPK (Control) | 32.03 | 29.74 | 37.50 | 33.42 | 38.80 | 36.05 |
| $T_2$: NPK+*Zn (s) | 45.83 | 43.82 | 45.96 | 47.11 | 52.08 | 46.05 |
| $T_3$: NPK+**Zn (f) | 46.87 | 44.74 | 50.13 | 48.68 | 52.99 | 50.00 |
| $T_4$: NPK+Zn (s)+Zn (f) | 48.64 | 49.74 | 50.36 | 56.45 | 56.29 | 55.37 |
| $T_5$: NPK+**Fe (f) | 44.48 | 41.18 | 44.92 | 41.97 | 42.09 | 41.88 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 47.40 | 45.53 | 45.42 | 51.84 | 55.86 | 51.05 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 47.70 | 48.55 | 51.14 | 55.52 | 54.56 | 53.68 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 55.67 | 54.34 | 53.18 | 58.02 | 58.70 | 57.24 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 41.79 | 42.11 | 48.05 | 47.50 | 50.65 | 44.87 |
| **LSD (p=0.05)** | | | | | **V x N = NS** | **V x N = NS** |

| Table 9. Physical grain characteristics as affected by wheat varieties and nutrient management | | | | | | |
|---|---|---|---|---|---|---|
| **Treatment** | **Grain Appearance Score (Max 10)** | | **Hectolitre Weight (kg/hl)** | | **Grain Hardness (kg)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | |
| $V_1$: HD 2967 | 5.3 | 5.5 | 77.2 | 76.3 | 9.6 | 10.4 |
| $V_2$: PBW 621 | 5.5 | 5.7 | 77.5 | 76.7 | 11.3 | 11.6 |
| $V_3$: PBW 550 | 5.8 | 6.0 | 80.4 | 79.9 | 11.8 | 12.0 |
| **LSD (p=0.05)** | **0.3** | **0.2** | **1.0** | **1.4** | **0.8** | **0.7** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK (Control) | 5.1 | 5.2 | 77.1 | 76.1 | 9.2 | 9.5 |
| $T_2$: NPK+*Zn (s) | 5.2 | 5.3 | 77.7 | 77.5 | 10.8 | 10.9 |
| $T_3$: NPK+**Zn (f) | 5.3 | 5.4 | 78.1 | 77.4 | 10.6 | 11.2 |
| $T_4$: NPK+Zn (s)+Zn (f) | 5.4 | 5.6 | 78.2 | 77.5 | 11.0 | 11.3 |
| $T_5$: NPK+**Fe (f) | 5.4 | 5.5 | 77.2 | 77.4 | 10.0 | 10.4 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 5.7 | 5.9 | 78.4 | 77.5 | 11.0 | 11.5 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 5.8 | 6.0 | 78.8 | 78.3 | 11.4 | 11.6 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 6.1 | 6.0 | 78.9 | 78.4 | 12.4 | 12.8 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 5.6 | 5.8 | 78.5 | 78.1 | 11.4 | 11.6 |
| **LSD (p=0.05) : N** | **0.2** | **0.1** | **1.0** | **1.3** | **0.5** | **0.6** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 10. Chemical grain characteristics as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Protein content (%)** | | **SDS-Sedimentation value (cc)** | | **β-Carotene (ppm)** | | **Phenol Reaction Score (Max 10)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 11.22 | 11.23 | 42 | 43 | 4.98 | 5.43 | 3.8 | 3.6 |
| $V_2$: PBW 621 | 11.26 | 11.33 | 47 | 49 | 4.60 | 4.97 | 3.8 | 3.7 |
| $V_3$: PBW 550 | 11.88 | 11.94 | 49 | 50 | 4.80 | 5.23 | 3.7 | 3.5 |
| **LSD (p=0.05)** | **0.30** | **0.32** | **4** | **3** | **NS** | **NS** | **NS** | **NS** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 10.52 | 10.61 | 40 | 42 | 3.14 | 3.15 | 4.1 | 3.9 |
| $T_2$: NPK+*Zn (s) | 10.60 | 10.76 | 46 | 46 | 4.85 | 5.33 | 3.7 | 3.5 |
| $T_3$: NPK+**Zn (f) | 10.62 | 10.77 | 44 | 46 | 5.08 | 5.47 | 3.8 | 3.6 |
| $T_4$: NPK+Zn (s)+Zn (f) | 11.53 | 11.80 | 45 | 47 | 5.15 | 5.25 | 3.6 | 3.5 |
| $T_5$: NPK+**Fe (f) | 11.14 | 11.32 | 44 | 45 | 4.47 | 5.05 | 3.8 | 3.7 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 11.60 | 11.82 | 48 | 49 | 5.20 | 5.54 | 3.9 | 3.7 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 12.22 | 12.25 | 50 | 51 | 5.25 | 5.69 | 3.7 | 3.6 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 12.44 | 12.56 | 51 | 53 | 5.30 | 5.81 | 3.5 | 3.3 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 11.94 | 11.95 | 45 | 47 | 5.13 | 5.59 | 3.8 | 3.6 |
| **LSD (p=0.05) : N** | **0.65** | **0.84** | **2** | **2** | **0.34** | **0.31** | **NS** | **NS** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 11. Effect of wheat varieties and nutrient management on nitrogen content and uptake in grain, straw and crop | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nitrogen (grains)** | | | | **Nitrogen (straw)** | | | | **Total Nitogen uptake by crop (kg/ha)** | |
| | **Content (%)** | | **Uptake (kg/ha)** | | **Content (%)** | | **Uptake (kg/ha)** | | | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | | | |
| $V_1$: HD 2967 | 1.70 | 1.73 | 77.52 | 76.84 | 0.50 | 0.54 | 36.66 | 37.54 | 114.18 | 114.38 |
| $V_2$: PBW 621 | 1.71 | 1.75 | 81.07 | 85.65 | 0.51 | 0.55 | 37.93 | 36.98 | 118.99 | 122.63 |
| $V_3$: PBW 550 | 1.74 | 1.79 | 89.32 | 86.75 | 0.56 | 0.60 | 35.39 | 35.31 | 124.71 | 122.06 |
| **LSD (p=0.05)** | **NS** | **0.02** | **11.57** | **NS** | **0.03** | **0.04** | **2.05** | **1.75** | **NS** | **NS** |
| **Nutrient management (N)** | | | | | | | | | | |
| $T_1$: NPK (Control) | 1.64 | 1.68 | 59.22 | 55.56 | 0.43 | 0.48 | 27.72 | 26.60 | 86.94 | 82.15 |
| $T_2$: NPK+*Zn (s) | 1.69 | 1.72 | 81.05 | 78.54 | 0.48 | 0.52 | 32.87 | 32.98 | 113.91 | 111.51 |
| $T_3$: NPK+**Zn (f) | 1.71 | 1.75 | 85.49 | 83.66 | 0.50 | 0.55 | 35.12 | 36.31 | 120.61 | 119.97 |
| $T_4$: NPK+Zn (s)+Zn (f) | 1.78 | 1.82 | 92.14 | 98.01 | 0.60 | 0.64 | 42.02 | 44.76 | 134.16 | 142.77 |
| $T_5$: NPK+**Fe (f) | 1.66 | 1.70 | 72.76 | 70.85 | 0.46 | 0.49 | 31.38 | 29.23 | 104.14 | 100.08 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 1.73 | 1.77 | 85.74 | 87.57 | 0.54 | 0.58 | 38.19 | 38.53 | 123.93 | 126.10 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 1.76 | 1.80 | 89.99 | 94.65 | 0.60 | 0.61 | 42.58 | 42.36 | 132.58 | 137.01 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 1.80 | 1.84 | 100.53 | 104.02 | 0.63 | 0.67 | 49.75 | 48.86 | 150.28 | 152.88 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 1.67 | 1.71 | 78.21 | 76.65 | 0.47 | 0.51 | 33.16 | 32.40 | 111.36 | 109.05 |
| **LSD (p=0.05) : N** | **0.01** | **0.02** | **9.24** | **8.28** | **0.02** | **0.02** | **1.17** | **1.33** | **9.37** | **8.33** |
| **V x N** | **0.02** | **0.03** | **NS** | **NS** | **NS** | **NS** | **2.03** | **2.30** | **NS** | **NS** |

| Table 12. Interaction effect of varieties and nutrient management on N Content in grain (%) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 1.59 | 1.65 | 1.68 | 1.62 | 1.68 | 1.73 |
| $T_2$: NPK+*Zn (s) | 1.68 | 1.67 | 1.71 | 1.70 | 1.72 | 1.75 |
| $T_3$: NPK+**Zn (f) | 1.71 | 1.69 | 1.73 | 1.73 | 1.74 | 1.78 |
| $T_4$: NPK+Zn (s)+Zn (f) | 1.78 | 1.76 | 1.80 | 1.81 | 1.85 | 1.85 |
| $T_5$: NPK+**Fe (f) | 1.61 | 1.66 | 1.70 | 1.64 | 1.75 | 1.75 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 1.73 | 1.72 | 1.75 | 1.76 | 1.76 | 1.80 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 1.76 | 1.74 | 1.77 | 1.79 | 1.78 | 1.83 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 1.80 | 1.79 | 1.82 | 1.83 | 1.83 | 1.87 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 1.64 | 1.67 | 1.74 | 1.66 | 1.71 | 1.76 |
| **LSD (p=0.05)** | **V x N = 0.02** | | | **V x N = 0.03** | | |

| Table 13. Interaction effect of varieties and nutrient management on N uptake in wheat straw (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 28.22 | 23.22 | 31.71 | 24.30 | 25.93 | 28.79 |
| $T_2$: NPK+*Zn (s) | 34.76 | 35.66 | 28.74 | 33.23 | 32.93 | 33.28 |
| $T_3$: NPK+**Zn (f) | 36.36 | 36.33 | 34.03 | 33.96 | 36.87 | 37.50 |
| $T_4$: NPK+Zn (s)+Zn (f) | 42.05 | 43.60 | 39.20 | 48.66 | 45.57 | 39.71 |
| $T_5$: NPK+**Fe (f) | 25.55 | 39.62 | 38.36 | 29.83 | 32.07 | 25.16 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 38.15 | 42.05 | 33.24 | 38.73 | 37.84 | 38.86 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 42.52 | 42.93 | 35.72 | 44.68 | 44.85 | 38.11 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 51.26 | 55.46 | 41.55 | 52.32 | 49.30 | 44.69 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 31.03 | 32.19 | 35.66 | 33.52 | 28.81 | 33.71 |
| **LSD (p=0.05)** | **V x N =2.03** | | | **V x N = 2.30** | | |

| Table 14. Nutrient concentration as influenced by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nutrient Concentration (µg/g)** | | | | | | | |
| | **Zinc** | | | | **Iron** | | | |
| | **Grain** | | **Straw** | | **Grain** | | **Straw** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$: HD 2967 | 27.07 | 26.55 | 28.32 | 27.79 | 36.70 | 35.88 | 213.92 | 212.33 |
| $V_2$: PBW 621 | 28.83 | 28.67 | 30.52 | 30.26 | 36.99 | 36.28 | 208.50 | 215.30 |
| $V_3$: PBW 550 | 30.38 | 29.87 | 31.98 | 31.56 | 38.04 | 36.95 | 222.20 | 218.53 |
| **LSD (p=0.05)** | **0.59** | **0.74** | **1.31** | **0.59** | **0.80** | **0.30** | **1.11** | **2.82** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 23.64 | 22.48 | 21.87 | 21.44 | 31.31 | 30.67 | 202.29 | 197.58 |
| $T_2$: NPK+*Zn (s) | 25.33 | 24.76 | 27.40 | 26.74 | 33.47 | 31.85 | 208.59 | 205.61 |
| $T_3$: NPK+**Zn (f) | 29.40 | 29.11 | 30.91 | 30.53 | 34.64 | 33.64 | 212.61 | 207.72 |
| $T_4$: NPK+Zn (s)+Zn (f) | 34.83 | 34.48 | 36.28 | 36.13 | 37.64 | 37.33 | 216.21 | 217.24 |
| $T_5$: NPK+**Fe (f) | 23.66 | 23.65 | 24.41 | 24.17 | 42.82 | 41.23 | 231.29 | 229.28 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 30.55 | 31.48 | 33.03 | 31.96 | 36.31 | 34.89 | 213.88 | 211.91 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 31.92 | 31.55 | 34.31 | 33.93 | 37.11 | 35.74 | 220.17 | 215.93 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 36.99 | 36.60 | 37.66 | 37.48 | 38.47 | 38.91 | 212.54 | 219.92 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 24.62 | 23.83 | 26.57 | 26.46 | 43.43 | 43.04 | 236.29 | 233.10 |
| **LSD (p=0.05) : N** | **1.15** | **1.44** | **1.43** | **1.63** | **1.30** | **1.47** | **3.60** | **4.35** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 15. Nutrient uptake as influenced by wheat varieties and nutrient management | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nutrient Uptake (g/ha)** | | | | | | | | | | | |
| | **Zinc** | | | | | | **Iron** | | | | | |
| | **Grain** | | **Straw** | | **Total** | | **Grain** | | **Straw** | | **Total** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | | | | | |
| $V_1$: HD 2967 | 126.11 | 121.13 | 209.07 | 196.34 | 335.18 | 317.47 | 168.01 | 160.35 | 1566.67 | 1479.82 | 1734.68 | 1640.17 |
| $V_2$: PBW 621 | 138.30 | 143.61 | 230.53 | 206.17 | 368.83 | 349.78 | 176.02 | 178.45 | 1626.32 | 1448.45 | 1802.34 | 1626.90 |
| $V_3$: PBW 550 | 158.70 | 147.91 | 200.98 | 187.19 | 359.68 | 335.10 | 195.39 | 179.38 | 1408.13 | 1285.45 | 1603.52 | 1464.83 |
| **LSD (p=0.05)** | **13.76** | **14.61** | **24.07** | **21.33** | **32.53** | **31.87** | **18.27** | **10.25** | **80.30** | **35.40** | **75.45** | **40.25** |
| **Nutrient management (N)** | | | | | | | | | | | | |
| $T_1$: NPK (Control) | 78.62 | 68.12 | 140.15 | 118.50 | 218.77 | 186.60 | 113.21 | 101.52 | 1302.42 | 1094.20 | 1415.63 | 1195.72 |
| $T_2$: NPK+*Zn (s) | 121.75 | 113.28 | 185.69 | 168.87 | 307.44 | 282.15 | 160.56 | 145.43 | 1425.59 | 1302.95 | 1586.15 | 1448.38 |
| $T_3$: NPK+**Zn (f) | 146.83 | 138.22 | 216.07 | 201.44 | 362.90 | 339.66 | 173.20 | 160.98 | 1490.45 | 1371.38 | 1663.65 | 1532.36 |
| $T_4$: NPK+Zn (s)+Zn (f) | 180.62 | 185.83 | 253.81 | 252.05 | 434.43 | 437.88 | 195.05 | 200.99 | 1513.67 | 1494.80 | 1708.72 | 1677.79 |
| $T_5$: NPK+**Fe (f) | 103.57 | 98.67 | 166.95 | 143.84 | 270.52 | 242.51 | 187.60 | 171.85 | 1579.03 | 1364.48 | 1766.63 | 1536.33 |
| $T_6$: NPK+*Zn (s)+***$N_{50}$ | 151.82 | 149.13 | 232.86 | 211.81 | 384.68 | 360.94 | 180.05 | 172.57 | 1512.06 | 1407.31 | 1692.11 | 1579.88 |
| $T_7$: NPK+$N_{50}$+Zn (f) | 163.67 | 166.28 | 242.61 | 234.76 | 406.28 | 401.04 | 189.95 | 188.03 | 1560.16 | 1500.05 | 1750.11 | 1688.08 |
| $T_8$: NPK+Zn (s)+$N_{50}$+Zn (f) | 206.83 | 204.50 | 296.33 | 272.56 | 503.16 | 477.06 | 214.97 | 210.03 | 1753.61 | 1601.44 | 1968.58 | 1821.47 |
| $T_9$: NPK+$N_{50}$+Fe (f) | 115.58 | 106.83 | 187.29 | 167.36 | 302.87 | 274.19 | 203.67 | 193.12 | 1666.38 | 1480.26 | 1870.05 | 1683.38 |
| **LSD (p=0.05) : N** | **18.71** | **15.41** | **39.48** | **21.20** | **40.91** | **33.66** | **23.41** | **17.64** | **170.50** | **131.35** | **191.75** | **145.17** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

**Experiment 2**

**Impact of N, Mn and Cu on growth, producitivity, agronomic biofortification and quality of wheat.**

| Table 16. Effect of wheat varieties and nutrient management on crop emergence | | |
|---|---|---|
| **Treatment** | **Emergence count/$m^2$** | |
| | **2011-12** | **2012-13** |
| **Varieties (V)** | | |
| $V_1$ : HD 2967 | 205 | 195 |
| $V_2$ : PBW 621 | 205 | 195 |
| $V_3$ : PBW 550 | 200 | 191 |
| **LSD (p=0.05)** | **NS** | **NS** |
| **Nutrient management (N)** | | |
| $T_1$: NPK (Control) | 202 | 193 |
| $T_2$: NPK+*Mn (f) | 204 | 194 |
| $T_3$: NPK+*Cu (f) | 204 | 194 |
| $T_4$: NPK+Mn (f)+Cu (f) | 204 | 193 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 203 | 193 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 204 | 194 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 204 | 194 |
| **LSD (p=0.05) : N** | **NS** | **NS** |
| **V x N** | **NS** | **NS** |

***Foliar spray of 0.5% $MnSO_4$. $H_2O$ & 0.1% $CuSO_4$. $5H_2O$ separately at mid-boot, pre-milk and dough stages**

****N @ 50 Kg/ha applied at 80 DAS**

**DTPA extractable Mn in soil was 3.40 µg/g i.e. lower than the critical level (3.5 mg/kg)**

**DTPA extractable Cu in soil was 0.18 µg/g i.e. lower than the critical level (0.20 mg/kg)**

| Table 17. Periodic plant height as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Plant height (cm)** | | | | | | | |
| | **60 DAS** | | **90 DAS** | | **120 DAS** | | **At harvest** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 24.3 | 22.6 | 41.3 | 39.8 | 79.6 | 77.4 | 87.6 | 83.5 |
| $V_2$ : PBW 621 | 25.3 | 23.7 | 44.4 | 42.3 | 82.7 | 79.2 | 88.7 | 84.2 |
| $V_3$ : PBW 550 | 26.8 | 24.9 | 68.3 | 63.4 | 73.5 | 69.7 | 76.4 | 74.3 |
| **LSD (p=0.05)** | **NS** | **NS** | **5.9** | **4.8** | **5.8** | **4.5** | **5.5** | **7.0** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 26.1 | 24.2 | 42.2 | 40.4 | 72.4 | 67.2 | 78.5 | 74.4 |
| $T_2$: NPK+*Mn (f) | 26.5 | 24.5 | 49.6 | 47.4 | 74.6 | 74.5 | 83.1 | 80.4 |
| $T_3$: NPK+*Cu (f) | 25.1 | 23.9 | 44.2 | 42.8 | 73.1 | 68.7 | 80.1 | 75.6 |
| $T_4$: NPK+Mn (f)+Cu (f) | 26.2 | 23.5 | 55.0 | 53.2 | 81.1 | 78.2 | 88.5 | 83.5 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 25.2 | 23.7 | 54.3 | 51.4 | 83.7 | 80.3 | 86.2 | 84.4 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 25.7 | 24.1 | 46.3 | 47.4 | 78.4 | 71.7 | 81.6 | 81.5 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 25.4 | 23.8 | 56.8 | 54.0 | 84.8 | 80.3 | 89.6 | 86.6 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **2.8** | **2.0** | **1.7** | **1.3** | **2.0** | **1.6** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 18. Periodic dry matter accumulation as influenced by wheat varieties and nutrient management | | | | | | |
|---|---|---|---|---|---|---|
| **Treatment** | **Dry matter accumulation (q/ha)** | | | | | |
| | **60 DAS** | | **90 DAS** | | **120 DAS** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | |
| $V_1$ : HD 2967 | 16.4 | 14.3 | 30.3 | 27.4 | 110.2 | 111.7 |
| $V_2$ : PBW 621 | 17.5 | 15.4 | 39.4 | 36.3 | 114.3 | 116.3 |
| $V_3$ : PBW 550 | 18.9 | 16.3 | 54.5 | 50.4 | 108.1 | 108.8 |
| **LSD (p=0.05)** | **NS** | **NS** | **5.2** | **5.9** | **4.6** | **5.5** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK (Control) | 17.1 | 15.2 | 27.5 | 27.1 | 84.2 | 82.4 |
| $T_2$: NPK+*Mn (f) | 17.6 | 15.7 | 37.2 | 35.3 | 116.4 | 115.2 |
| $T_3$: NPK+*Cu (f) | 16.6 | 15.5 | 28.2 | 29.4 | 103.1 | 100.6 |
| $T_4$: NPK+Mn (f)+Cu (f) | 16.2 | 16.0 | 43.4 | 45.3 | 126.8 | 124.3 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 16.8 | 17.1 | 40.2 | 42.5 | 117.3 | 120.3 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 16.2 | 15.8 | 32.7 | 33.4 | 105.2 | 103.4 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 16.5 | 17.4 | 50.3 | 48.6 | 133.1 | 130.5 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **3.8** | **2.7** | **4.3** | **5.2** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 19. Leaf area index (LAI) at different phenological stages as influenced by wheat varieties and nutrient management | | | | | | |
|---|---|---|---|---|---|---|
| **Treatment** | **Leaf area Index (LAI)** | | | | | |
| | **60 DAS** | | **90 DAS** | | **120 DAS** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | |
| $V_1$ : HD 2967 | 2.48 | 2.42 | 4.67 | 4.62 | 3.75 | 3.69 |
| $V_2$ : PBW 621 | 2.47 | 2.44 | 4.81 | 4.77 | 3.88 | 3.83 |
| $V_3$ : PBW 550 | 2.52 | 2.47 | 4.55 | 4.51 | 3.56 | 3.52 |
| **LSD (p=0.05)** | **NS** | **NS** | **0.05** | **0.04** | **0.07** | **0.06** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK (Control) | 2.50 | 2.47 | 4.14 | 4.11 | 3.12 | 2.90 |
| $T_2$: NPK+*Mn (f) | 2.53 | 2.50 | 4.40 | 4.35 | 3.28 | 3.24 |
| $T_3$: NPK+*Cu (f) | 2.52 | 2.49 | 4.21 | 4.16 | 3.25 | 3.21 |
| $T_4$: NPK+Mn (f)+Cu (f) | 2.50 | 2.47 | 4.90 | 4.84 | 3.85 | 3.82 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 2.51 | 2.48 | 4.60 | 4.55 | 3.58 | 3.54 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 2.53 | 2.50 | 4.33 | 4.28 | 3.40 | 3.36 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 2.50 | 2.48 | 5.28 | 5.10 | 4.35 | 4.27 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **0.05** | **0.06** | **0.08** | **0.07** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 20. Periodic tiller count as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Tillers/m$^2$** | | | | | | | |
| | **60 DAS** | | **90 DAS** | | **120 DAS** | | **At harvest** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 314 | 311 | 340 | 338 | 323 | 320 | 318 | 315 |
| $V_2$ : PBW 621 | 316 | 312 | 345 | 340 | 327 | 323 | 324 | 320 |
| $V_3$ : PBW 550 | 311 | 307 | 323 | 320 | 307 | 305 | 304 | 300 |
| **LSD (p=0.05)** | **3** | **2** | **6** | **7** | **5** | **6** | **6** | **5** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 310 | 308 | 325 | 319 | 309 | 305 | 300 | 294 |
| $T_2$: NPK+*Mn (f) | 313 | 310 | 345 | 340 | 328 | 325 | 321 | 318 |
| $T_3$: NPK+*Cu (f) | 312 | 308 | 337 | 333 | 320 | 315 | 312 | 309 |
| $T_4$: NPK+Mn (f)+Cu (f) | 311 | 309 | 385 | 380 | 366 | 362 | 360 | 355 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 310 | 310 | 375 | 371 | 356 | 352 | 349 | 344 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 312 | 308 | 367 | 362 | 350 | 345 | 343 | 340 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 313 | 309 | 394 | 390 | 375 | 371 | 370 | 367 |
| **LSD (p=0.05) : N** | **NS** | **NS** | **7** | **9** | **8** | **10** | **7** | **9** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 21. Yield attributes as influenced by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Effective tillers/$m^2$** | | **Ear length (cm)** | | **Grains/ear** | | **1000-grain wt (g)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 315 | 310 | 9.1 | 8.8 | 37.7 | 36.3 | 40.5 | 38.7 |
| $V_2$ : PBW 621 | 319 | 312 | 9.9 | 9.3 | 42.9 | 41.2 | 40.6 | 39.6 |
| $V_3$ : PBW 550 | 300 | 295 | 10.4 | 10.5 | 46.7 | 44.6 | 43.5 | 42.6 |
| **LSD (p=0.05)** | **4** | **5** | **0.6** | **0.7** | **0.6** | **0.8** | **2.6** | **1.5** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 284 | 275 | 8.7 | 8.4 | 41.0 | 39.3 | 37.8 | 35.6 |
| $T_2$: NPK+*Mn (f) | 315 | 312 | 9.1 | 9.7 | 41.9 | 40.4 | 41.4 | 39.7 |
| $T_3$: NPK+*Cu (f) | 308 | 305 | 9.2 | 9.1 | 41.2 | 39.9 | 39.3 | 37.5 |
| $T_4$: NPK+Mn (f)+Cu (f) | 355 | 349 | 10.4 | 10.3 | 43.7 | 42.0 | 43.9 | 43.7 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 345 | 340 | 10.1 | 9.8 | 42.9 | 41.5 | 42.8 | 41.1 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 337 | 335 | 9.6 | 9.3 | 41.8 | 39.9 | 40.5 | 39.6 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 364 | 355 | 10.7 | 10.4 | 44.6 | 42.3 | 45.0 | 44.7 |
| **LSD (p=0.05) : N** | **6** | **8** | **0.4** | **0.5** | **0.6** | **0.7** | **1.0** | **1.3** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **1.0** | **1.0** | **NS** | **NS** |

| Table 22. Interaction effect of varieties and nutrient management on number of grains/ear | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 35.9 | 41.1 | 45.3 | 34.7 | 40.0 | 43.1 |
| $T_2$: NPK+Mn (f) | 37.1 | 41.4 | 46.6 | 36.7 | 40.1 | 44.4 |
| $T_3$: NPK+Cu (f) | 36.3 | 42.1 | 45.4 | 35.5 | 40.9 | 43.2 |
| $T_4$: NPK+Mn (f)+Cu (f) | 39.1 | 44.2 | 48.0 | 38.0 | 42.4 | 45.6 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 38.4 | 43.2 | 47.1 | 37.3 | 41.3 | 45.8 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 36.1 | 42.1 | 47.5 | 35.1 | 41.2 | 43.3 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 39.4 | 44.1 | 49.5 | 37.1 | 42.7 | 47.2 |
| **LSD (p=0.05)** | **V × N = 1.0** | | | **V × N = 1.2** | | |

| Table 23. Yield and harvest index as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Grain yield (q/ha)** | | **Straw yield (q/ha)** | | **Biological yield (q/ha)** | | **Harvest Index** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 46.01 | 44.90 | 63.06 | 69.83 | 109.50 | 114.73 | 42.02 | 39.14 |
| $V_2$ : PBW 621 | 44.69 | 45.33 | 67.36 | 72.03 | 112.50 | 117.35 | 39.72 | 38.63 |
| $V_3$ : PBW 550 | 46.45 | 47.09 | 61.03 | 63.28 | 107.91 | 109.91 | 43.05 | 42.84 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **0.38** | **0.45** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 29.25 | 32.51 | 45.22 | 52.79 | 74.47 | 85.30 | 39.28 | 38.11 |
| $T_2$: NPK+*Mn (f) | 47.57 | 44.93 | 66.79 | 69.22 | 114.36 | 114.15 | 41.60 | 39.36 |
| $T_3$: NPK+*Cu (f) | 42.53 | 43.54 | 58.56 | 67.17 | 101.09 | 109.57 | 42.07 | 39.74 |
| $T_4$: NPK+Mn (f)+Cu (f) | 52.65 | 51.73 | 72.13 | 76.45 | 124.78 | 128.17 | 42.19 | 40.36 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 48.70 | 47.43 | 66.54 | 70.16 | 115.24 | 119.00 | 42.25 | 39.85 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 45.14 | 45.20 | 60.89 | 67.04 | 109.03 | 112.27 | 41.40 | 40.26 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 54.15 | 53.71 | 76.59 | 75.81 | 130.74 | 129.52 | 41.42 | 41.46 |
| **LSD (p=0.05) : N** | **4.33** | **4.31** | **7.00** | **4.69** | **11.90** | **8.60** | **0.75** | **0.62** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 24. Effect of wheat varieties and nutrient management on grain yield (q/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **HD 2967** | | **PBW 621** | | **PBW 550** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| $T_1$: NPK (Control) | 30.25 | 29.43 | 28.95 | 32.03 | 28.56 | 36.07 |
| $T_2$: NPK+*Mn (f) | 51.22 | 45.16 | 43.15 | 43.10 | 48.35 | 46.52 |
| $T_3$: NPK+*Cu (f) | 39.89 | 41.54 | 43.50 | 42.97 | 44.19 | 42.71 |
| $T_4$: NPK+Mn (f)+Cu (f) | 52.13 | 50.95 | 49.53 | 51.86 | 56.30 | 52.38 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 50.82 | 49.30 | 46.53 | 49.48 | 48.74 | 47.66 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 43.01 | 44.92 | 44.32 | 44.53 | 48.09 | 46.22 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 54.73 | 52.99 | 56.82 | 53.29 | 50.90 | 54.85 |
| **LSD (p=0.05)** | | | | | **V x N = NS** | **V x N = NS** |

| Table 25. Physical grain characteristics as affected by wheat varieties and nutrient management | | | | | | |
|---|---|---|---|---|---|---|
| **Treatment** | **Grain Appearance Score (Max 10)** | | **Hectolitre Weight (kg/hl)** | | **Grain Hardness (kg)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | |
| $V_1$ : HD 2967 | 5.0 | 5.4 | 75.1 | 74.9 | 9.2 | 9.7 |
| $V_2$ : PBW 621 | 5.3 | 5.5 | 75.7 | 75.4 | 10.8 | 11.0 |
| $V_3$ : PBW 550 | 5.7 | 5.8 | 79.5 | 79.4 | 11.9 | 12.1 |
| **LSD (p=0.05)** | **0.2** | **0.2** | **1.2** | **1.7** | **1.0** | **0.9** |
| **Nutrient management (N)** | | | | | | |
| $T_1$: NPK (Control) | 5.0 | 5.1 | 75.2 | 75.2 | 9.1 | 9.6 |
| $T_2$: NPK+*Mn (f) | 5.2 | 5.4 | 77.2 | 76.8 | 10.4 | 10.8 |
| $T_3$: NPK+*Cu (f) | 5.2 | 5.3 | 76.7 | 75.5 | 10.2 | 10.4 |
| $T_4$: NPK+Mn (f)+Cu (f) | 5.4 | 5.5 | 77.7 | 77.4 | 11.1 | 11.5 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 5.5 | 5.7 | 76.9 | 76.9 | 10.8 | 11.2 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 5.4 | 5.6 | 76 | 76.7 | 10.7 | 10.8 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 5.8 | 6 | 77.9 | 77.8 | 11.8 | 12.1 |
| **LSD (p=0.05) : N** | **0.1** | **0.2** | **1.1** | **1.5** | **0.5** | **0.4** |
| **V x N** | **0.2** | **0.1** | **NS** | **NS** | **NS** | **NS** |

| Table 26. Chemical grain characteristics as affected by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Protein content (%)** | | **SDS-Sedimentation value (cc)** | | **β-Carotene (ppm)** | | **Phenol Reaction Score (Max 10)** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 12.05 | 12.15 | 45 | 47 | 5.37 | 5.69 | 3.9 | 3.8 |
| $V_2$ : PBW 621 | 12.24 | 12.31 | 48 | 50 | 4.80 | 4.93 | 3.7 | 3.6 |
| $V_3$ : PBW 550 | 12.33 | 12.62 | 53 | 55 | 4.82 | 5.17 | 3.6 | 3.4 |
| **LSD (p=0.05)** | **NS** | **NS** | **3** | **4** | **0.12** | **0.35** | **NS** | **NS** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 11.33 | 11.50 | 44 | 46 | 3.34 | 3.42 | 4.0 | 3.9 |
| $T_2$: NPK+*Mn (f) | 11.95 | 12.19 | 48 | 49 | 5.21 | 5.51 | 3.8 | 3.6 |
| $T_3$: NPK+*Cu (f) | 11.69 | 11.97 | 46 | 48 | 4.92 | 5.25 | 3.8 | 3.6 |
| $T_4$: NPK+Mn (f)+Cu (f) | 12.19 | 12.31 | 48 | 51 | 5.2 | 5.36 | 3.5 | 3.4 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 12.57 | 12.74 | 51 | 53 | 5.44 | 5.63 | 3.6 | 3.5 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 12.52 | 12.65 | 49 | 52 | 5.37 | 5.59 | 3.8 | 3.7 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 13.17 | 13.21 | 53 | 55 | 5.68 | 5.98 | 3.4 | 3.3 |
| **LSD (p=0.05) : N** | **0.44** | **0.52** | **1** | **1** | **0.18** | **0.31** | **NS** | **NS** |
| **V x N** | **NS** | **NS** | **2** | **3** | **NS** | **NS** | **NS** | **NS** |

| Table 27. Interaction effect of varieties and nutrient management on Grain Appearance Score (Max 10) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 4.7 | 5.0 | 5.3 | 4.9 | 5.1 | 5.3 |
| $T_2$: NPK+Mn (f) | 4.9 | 5.2 | 5.6 | 5.3 | 5.3 | 5.7 |
| $T_3$: NPK+Cu (f) | 4.8 | 5.2 | 5.7 | 5.1 | 5.2 | 5.7 |
| $T_4$: NPK+Mn (f)+Cu (f) | 4.9 | 5.4 | 5.8 | 5.3 | 5.4 | 5.8 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 5.0 | 5.6 | 5.9 | 5.5 | 5.6 | 6.0 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 5.0 | 5.3 | 5.8 | 5.5 | 5.5 | 5.9 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 5.4 | 5.7 | 6.0 | 5.8 | 6.1 | 6.2 |
| **LSD (p=0.05)** | **V × N = 0.22** | | | **V × N = 0.1** | | |

| Table 28. Interaction effect of varieties and nutrient management on SDS-Sedimentation Value (cc) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **2011-12** | | | **2012-13** | | |
| | **HD 2967** | **PBW 621** | **PBW 550** | **HD 2967** | **PBW 621** | **PBW 550** |
| $T_1$: NPK (Control) | 39 | 45 | 49 | 41 | 47 | 51 |
| $T_2$: NPK+Mn (f) | 45 | 48 | 52 | 47 | 48 | 53 |
| $T_3$: NPK+Cu (f) | 42 | 46 | 49 | 45 | 48 | 51 |
| $T_4$: NPK+Mn (f)+Cu (f) | 45 | 46 | 52 | 48 | 49 | 56 |
| $T_5$: NPK+$N_{50}$+Mn (f) | 49 | 50 | 55 | 51 | 51 | 57 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 45 | 48 | 53 | 49 | 51 | 56 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 50 | 51 | 58 | 51 | 53 | 60 |
| **LSD (p=0.05)** | **V × N = 2** | | | **V × N = 3** | | |

| Table 29. Effect of wheat varieties and nutrient applications on nitrogen content and uptake in grain, straw and crop | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nitrogen (grains)** | | | | **Nitrogen (straw)** | | | | **Total Nitogen uptake by crop (kg/ha)** | |
| | **Content (%)** | | **Uptake (kg/ha)** | | **Content (%)** | | **Uptake (kg/ha)** | | | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | | | |
| $V_1$ : HD 2967 | 1.72 | 1.76 | 79.14 | 79.02 | 0.45 | 0.48 | 28.38 | 33.52 | 107.51 | 112.54 |
| $V_2$ : PBW 621 | 1.77 | 1.82 | 79.10 | 82.48 | 0.51 | 0.54 | 34.35 | 38.90 | 113.45 | 121.38 |
| $V_3$ : PBW 550 | 1.86 | 1.89 | 86.40 | 88.13 | 0.56 | 0.58 | 34.18 | 36.70 | 120.58 | 124.83 |
| **LSD (p=0.05)** | **0.03** | **0.04** | **NS** | **5.74** | **0.05** | **0.07** | **2.94** | **1.75** | **7.79** | **6.79** |
| **Nutrient management (N)** | | | | | | | | | | |
| $T_1$: NPK (Control) | 1.73 | 1.78 | 50.61 | 57.87 | 0.44 | 0.48 | 19.90 | 25.34 | 70.51 | 83.21 |
| $T_2$: NPK+*Mn (f) | 1.77 | 1.81 | 84.20 | 81.32 | 0.50 | 0.53 | 33.40 | 36.69 | 117.60 | 118.00 |
| $T_3$: NPK+*Cu (f) | 1.75 | 1.79 | 74.42 | 75.91 | 0.46 | 0.49 | 26.94 | 32.91 | 101.36 | 108.82 |
| $T_4$: NPK+Mn (f)+Cu (f) | 1.82 | 1.87 | 95.83 | 96.74 | 0.55 | 0.58 | 39.67 | 44.34 | 135.50 | 141.08 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 1.79 | 1.84 | 87.17 | 89.82 | 0.53 | 0.55 | 35.27 | 38.59 | 122.43 | 128.40 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 1.76 | 1.81 | 79.45 | 81.85 | 0.49 | 0.51 | 29.84 | 34.19 | 109.28 | 116.04 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 1.85 | 1.89 | 100.18 | 101.51 | 0.58 | 0.61 | 44.42 | 46.24 | 144.60 | 147.76 |
| **LSD (p=0.05) : N** | **0.01** | **0.01** | **10.51** | **7.04** | **0.01** | **0.01** | **0.71** | **0.76** | **10.61** | **6.85** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **0.01** | **0.02** | **1.22** | **1.32** | **NS** | **NS** |

| Table 30. Interaction effect of varieties and nutrient management on N content in straw (%) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management (N)** | **Varieties (V)** | | | | | |
| | **HD 2967** | | **PBW 621** | | **PBW 550** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| $T_1$: NPK (Control) | 0.41 | 0.44 | 0.44 | 0.48 | 0.47 | 0.51 |
| $T_2$: NPK+*Mn (f) | 0.44 | 0.47 | 0.51 | 0.54 | 0.54 | 0.57 |
| $T_3$: NPK+*Cu (f) | 0.42 | 0.45 | 0.45 | 0.49 | 0.51 | 0.53 |
| $T_4$: NPK+Mn (f)+Cu (f) | 0.47 | 0.51 | 0.56 | 0.59 | 0.61 | 0.63 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 0.45 | 0.49 | 0.54 | 0.57 | 0.59 | 0.60 |
| $T_6$: NPK+$N_{50}$+ Cu (f) | 0.43 | 0.46 | 0.48 | 0.51 | 0.55 | 0.55 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 0.51 | 0.53 | 0.59 | 0.63 | 0.64 | 0.66 |
| **LSD (p=0.05)** | | | | | **V x N =0.01** | **V x N =0.02** |

| Table 31. Interaction effect of varieties and nutrient management on N uptake in wheat straw (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Nutrient management** | **Varieties (V)** | | | | | |
| | **HD 2967** | | **PBW 621** | | **PBW 550** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| $T_1$: NPK (Control) | 16.10 | 20.99 | 23.24 | 25.99 | 26.94 | 28.64 |
| $T_2$: NPK+*Mn (f) | 31.13 | 31.83 | 39.48 | 41.03 | 35.24 | 36.40 |
| $T_3$: NPK+*Cu (f) | 29.42 | 32.11 | 27.91 | 33.69 | 28.53 | 32.46 |
| $T_4$: NPK+Mn (f)+Cu (f) | 36.56 | 39.54 | 47.44 | 45.33 | 41.00 | 47.17 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 34.01 | 35.02 | 39.17 | 41.16 | 37.37 | 40.01 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 28.83 | 32.23 | 32.55 | 36.14 | 30.97 | 32.78 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 37.35 | 42.70 | 48.59 | 52.94 | 51.47 | 54.50 |
| **LSD (p=0.05)** | | | | | **V x N = 1.22** | **V x N = 1.32** |

| Table 32. Nutrient concentration as influenced by wheat varieties and nutrient management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nutrient concentration (µg/g)** | | | | | | | |
| | **Manganese** | | | | **Copper** | | | |
| | **Grain** | | **Straw** | | **Grain** | | **Straw** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | |
| $V_1$ : HD 2967 | 32.34 | 31.87 | 29.99 | 28.24 | 4.65 | 4.01 | 3.80 | 3.06 |
| $V_2$ : PBW 621 | 32.38 | 31.00 | 28.69 | 27.57 | 4.24 | 3.72 | 3.25 | 2.77 |
| $V_3$ : PBW 550 | 31.84 | 30.49 | 27.58 | 26.34 | 4.72 | 4.03 | 3.88 | 3.08 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **NS** | **0.18** | **0.19** | **0.17** | **0.18** |
| **Nutrient management (N)** | | | | | | | | |
| $T_1$: NPK (Control) | 25.62 | 25.25 | 20.17 | 19.76 | 3.40 | 2.99 | 2.41 | 2.02 |
| $T_2$: NPK+*Mn (f) | 32.88 | 31.73 | 28.89 | 27.21 | 3.82 | 3.10 | 2.73 | 2.15 |
| $T_3$: NPK+*Cu (f) | 27.92 | 27.67 | 24.44 | 22.58 | 4.31 | 3.55 | 3.32 | 2.60 |
| $T_4$: NPK+Mn (f)+Cu (f) | 36.53 | 36.44 | 35.59 | 33.65 | 5.39 | 4.62 | 4.40 | 3.67 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 34.56 | 31.94 | 28.98 | 27.45 | 4.01 | 3.24 | 3.02 | 2.29 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 31.28 | 27.36 | 25.86 | 23.59 | 4.92 | 4.15 | 3.93 | 3.20 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 37.55 | 38.46 | 37.34 | 37.46 | 5.92 | 5.82 | 5.60 | 4.88 |
| **LSD (p=0.05) : N** | **2.54** | **2.41** | **2.79** | **2.74** | **0.42** | **0.26** | **0.34** | **0.28** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

| Table 33. Nutrient uptake as influenced by wheat varieties and nutrient management | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Nutrient Uptake (g/ha)** | | | | | | | | | | | |
| | **Manganese** | | | | | | **Copper** | | | | | |
| | **Grain** | | **Straw** | | **Total** | | **Grain** | | **Straw** | | **Total** | |
| | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** | **11-12** | **12-13** |
| **Varieties (V)** | | | | | | | | | | | | |
| $V_1$ : HD 2967 | 148.79 | 143.09 | 189.12 | 197.20 | 337.90 | 340.29 | 21.39 | 18.00 | 23.96 | 21.37 | 45.35 | 39.37 |
| $V_2$ : PBW 621 | 144.69 | 140.50 | 193.26 | 198.59 | 337.95 | 339.09 | 18.95 | 16.86 | 21.89 | 19.95 | 40.84 | 36.81 |
| $V_3$ : PBW 550 | 147.89 | 142.17 | 168.35 | 166.68 | 316.24 | 308.85 | 21.92 | 18.98 | 23.68 | 19.49 | 45.60 | 38.47 |
| **LSD (p=0.05)** | **NS** | **NS** | **NS** | **11.79** | **NS** | **20.50** | **2.95** | **1.00** | **NS** | **1.75** | **5.53** | **1.52** |
| **Nutrient management (N)** | | | | | | | | | | | | |
| $T_1$: NPK (Control) | 74.95 | 82.09 | 91.21 | 104.31 | 166.16 | 186.40 | 9.95 | 9.72 | 10.89 | 10.66 | 20.84 | 20.38 |
| $T_2$: NPK+*Mn (f) | 156.42 | 142.55 | 192.96 | 188.35 | 349.38 | 330.90 | 18.17 | 13.92 | 18.23 | 14.87 | 36.40 | 28.79 |
| $T_3$: NPK+*Cu (f) | 118.73 | 117.34 | 143.15 | 151.67 | 261.88 | 269.01 | 18.33 | 15.46 | 19.44 | 17.46 | 37.77 | 32.92 |
| $T_4$: NPK+Mn (f)+Cu (f) | 192.34 | 188.50 | 256.71 | 257.25 | 449.05 | 445.76 | 28.38 | 23.9 | 31.73 | 28.09 | 60.11 | 56.47 |
| $T_5$: NPK+**$N_{50}$+Mn (f) | 168.30 | 155.91 | 192.83 | 192.59 | 361.13 | 348.50 | 19.53 | 15.37 | 20.09 | 16.05 | 39.62 | 31.42 |
| $T_6$: NPK+$N_{50}$+Cu (f) | 141.20 | 123.73 | 157.46 | 158.15 | 298.66 | 281.88 | 22.21 | 18.76 | 23.93 | 21.44 | 46.14 | 64.90 |
| $T_7$: NPK+$N_{50}$+Mn (f)+Cu (f) | 203.33 | 204.50 | 285.99 | 283.98 | 489.32 | 490.55 | 32.06 | 31.26 | 42.89 | 37.00 | 74.95 | 68.26 |
| **LSD (p=0.05) : N** | **23.60** | **16.34** | **27.59** | **19.06** | **49.74** | **34.57** | **2.91** | **1.73** | **3.50** | **2.75** | **5.97** | **5.90** |
| **V x N** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

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| | | |
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