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Improvement of Grain Yield, Nutritional and Antinutritional Quality, and Seed Physiological Performance of Wheat by NPK Fertilization

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ABSTRACT

The present research was conducted to study the effect of NPK fertilization on wheat grain yield, minerals concentration, grain quality, gluten, pentosan, and phytate phosphorous (phy-P) content, and the influence of maternal plant NPK fertilization on the seed physiological attributes during the germination period. NPK treatments comprised a control, where no fertilizer was applied (T_0), and two levels of NPK fertilizer: T_1 (110 kg N+60 kg P_2O_5+55 kg K_2O ha^{-1}), and T_2 (200 kg N+120 kg P_2O_5+100 kg K_2O ha^{-1}). Winter wheat was grown in a greenhouse during the growing season of 2015-16, following randomized complete block design with 4 replicates. The results indicated that a high level of NPK (T_2) fertilization increased the grain yield, crude protein, water-soluble pentosan, and dry gluten, up to 151.6, 65.3, 40.5, and 408.9% compared to the control, respectively. It also enhanced the grain mineral concentration, but did not affect the grain starch significantly. Grain phy-P was increased with a high NPK fertilization and, interestingly, the level of phytase enzyme was also increased up to 46% in T_2 compared to the control. Moreover, maternal plant NPK fertilization enhanced seed germination percentage, seedling fresh weight, phytase activity, inorganic phosphorus, and phy-P metabolism during the germination period. From the results of this study, it was concluded that grain nutritional quality was improved with increasing NPK rates, but antinutritional compound phy-P was also increased, while it may enhance seed viability, germination, and seedling vigor.

Keywords: Germination, Pentosan, Phytate, Wheat.

INTRODUCTION

Sustainable agricultural productivity and ensuring food security is possible through a precise and wise management of nutrients. Application of fertilizer adequately enhances the yield per unit area, improves grain quality, and bread quality of wheat. Nitrogen is an important component of proteins, nucleic acids, enzymes, coenzymes, and chlorophyll, and it contributes to the biochemical processes of the plant (Benin *et al*., 2012). Nitrogen fertilization at anthesis, is more effective in the synthesis of a high grain protein content than an earlier application (Wuest and Cassman 1992). Sufficient N fertilization results in the production of higher productive tillers and an increased number of spikes, number of grains per spike, grain yield, and biological yield. Phosphorus (P) fertilization of wheat crop significantly increased the plant height, number of tillers per plant, the straw and grain yield, and P uptake in grain over a control (Alam *et al*., 2003). More than 70% of the total P is stored in the grain as phytate (Rosa *et al*., 1999). The phy-P is an anti-nutritional factor that binds with proteins and some important micronutrients, such as iron and zinc, and significantly reduces the availability of these nutrients (Raboy, 2001). Accordingly,

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it is necessary to reduce the concentration of such anti-nutrient compounds in wheat grains by proper nutrient management. Potassium (K) plays a vital role in the biochemical functions of the plants like improvement of protein and carbohydrates, activating various enzymes, enhancement of fat concentration, developing drought tolerance, and resistance to lodging and frost (Marschner, 1995). An optimum dose of K increases the number of effective tillers, grains per spike, 1,000-grain weight, grain yield, straw yield, and protein content of wheat (Alam *et al*., 2009).

Pentosan is a major fiber component of the non-starch polysaccharides in cereal, which is called flour gum or hemicellulose. It affects food absorption in the human body, and decreases absorption of lipids and cholesterol and, therefore, plays a key role in the human diet (Mohammadkhani, 2005). Pentosans are important components of dough in which they bind water and contribute to the formation of viscous dough (Buksa *et al*., 2010). Water-soluble pentosan has a positive effect on the bread-making quality of wheat flour (Courtin and Delcour, 2002). Gluten is composed of glutenins and gliadins, which play an important role in the baking quality of bread due to their influence on the water absorption capacity, elasticity, and extensibility of dough and, thus, affect the flour quality of wheat (Torbica *et al*., 2007). Phytase (myoinositol hexaphosphate phosphohydrolase) is an enzyme which catalyzes the hydrolysis of phytate to inositol and orthophosphate, and helps in the bioavailability of P. Seed germination increases phytase activity by *de novo* synthesis of this enzyme during germination (Sung *et al*., 2005).

Investigation on the effects of macronutrients on the grain yield, quality, anti-nutrient compounds, and seed quality attributes, deserves more attention. On the other hand, the effects of NPK fertilization on the grain pentosan, gluten, phy-P, and physiological changes during seed germination have not been much studied. Therefore, the present experiment was conducted with the aim to study the effect of NPK fertilization on the wheat yield, grain quality, and anti-nutrient content, and the influence of maternal plant NPK nutrition on the seed germination, establishment, and physiological changes during seed germination.

MATERIALS AND METHODS

Plant Material and Growth Conditions

The wheat cultivar Minaminokaori was grown in a vinyl greenhouse in Hiroshima University with natural sunlight and temperature to prevent nutrient leaching due to rainfall. Containers (30 cm in width, 1.5 m in length, and 18 cm in depth) were used and filled with a mixture of regosol and aerobic compost (2:1). Chemical analysis of this mixture showed that it contained: 0.20% total N, 6.84 mg kg^{-1} available P, and 79.85 mg kg^{-1} available K. Furthermore, 1 ton ha^{-1} of dolomitic calcium magnesium carbonate was mixed with the soil to adjust the pH (H_2O) to 6.5.

This study comprised a control, where no fertilizer was applied (T_0), and two levels of NPK fertilizer: T_1 (110 kg N+60 kg P_2O_5+55 kg K_2O ha^{-1}), and T_2 (200 kg N+120 kg P_2O_5+100 kg K_2O ha^{-1}). The sources of NPK were urea, single super phosphate, and potassium chloride, respectively. All amount of P and K, and a half dose of N were applied before sowing, and the remaining N was applied in two equal splits at the tillering and anthesis stages. Wheat seeds were sown in the third week of November 2015, then, 10-day-old seedlings were transplanted into the containers at a 10-cm spacing, following a randomized complete block design with 4 replicates. All the recommended agronomic practices were followed for raising the crops during the experiment.

Grain Yield

Mature spikes were collected, oven dried at 80°C for 48 hours, threshed, and the grain yield was recorded and expressed in kg per hectare.

Determination of Grain Minerals

Samples of mature seeds were ground finely with a vibrating sample mill (TI-100, Heiko, Japan) and the concentrations of grain minerals were measured. Finely ground samples were digested by H_2SO_4-H_2O_2 and the K content was measured using a flame photometer (ANA 135, Tokyo Photoelectric, Tokyo, Japan). Ca, Mg, and Zn were measured by an atomic absorption flame emission spectrophotometer (AA-6200, Shimadzu, Japan). The total P was determined by a UV-Spectrophotometer (U-3310, Hitachi Co. Ltd. Tokyo, Japan) following the molybdenum reaction solution method suggested by Chen *et al*. (1956). Grain inorganic P (Pi) was extracted in trichloroacetic acid (12.5%)+$MgCl_2$ (2 mmol L^{-1}) while stirring overnight, and Pi was measured colorimetrically (Raboy and Dickinson 1984). The total nitrogen was measured using the Kjeldahl method after sample digestion with concentrated H_2SO_4 and H_2O_2.

Determination of Grain Quality

Starch was measured using the anthrone-sulfuric acid method (Spiro, 1966). Crude protein was calculated by multiplying the total N content by 5.47 (as proposed by Fujihara *et al*., 2008). Grain total pentosan was measured following the orcinol-HCl method, where finely ground samples were hydrolyzed with 2N HCl in boiling water for 2.5 hours, and centrifuged. Then, a specific amount of supernatant was transferred to new test tubes and reaction regents ($FeCl_3$ and Orcinol) were added and vortexed. The tubes were heated in boiling water for 30 minutes, cooled, and the absorbance was measured using a spectrophotometer. Water-soluble pentosan was extracted by hydrolyzing flour samples in distilled water with shaking for 2 hours at 30°C. Then, 4N HCl was added to the aliquots of the supernatant and placed in boiling water for 2 hours, and allowed to cool, and water-soluble pentosan was estimated by a spectrophotometer, using $FeCl_3$-orcinol reagents (Hashimoto *et al*., 1986). Gluten was measured according to (AACC) international approved method 38-10, by hand washing with 30 minutes resting time, and the result was expressed as dry gluten percentage. Phy-P was measured following the method suggested by Raboy and Dickinson (1984) where aliquots of flour were extracted in extraction media (0.2M HCl: 10% Na_2SO_4) overnight at 4°C with shaking. Extracts were centrifuged, and phytate P was obtained as a ferric precipitate and assayed for P using ammonium molybdate reaction reagent.

Germination Experiment

To determine the effect of maternal plant NPK fertilization on the growth and physiological performance of produced seeds, 200 seeds of 4 replicates were planted on germination wetted papers and placed in a germinator at 23°C for 7 days. Samples were taken every day, frozen with liquid N, and stored under -80°C. The data on phytase activity, phy-P content, and Pi content were recorded daily in the laboratory of plant nutritional physiology, faculty of applied biological science, Hiroshima University as follow.

Seed Germination Test and Determination of Physiological Attributes

Normal seedlings were counted on the 7th day of germination and the result was expressed in percent. Seedlings were harvested on the 7th day of germination and fresh weight was recorded. To measure phytase activity, fresh samples were ground with liquid nitrogen, transferred to Erlenmeyer flasks, and a buffer solution

(Na-Phytate+Sodium acetate) was added. Then, the samples were shaken for 30 minutes at 37°C. Subsequently, aliquots of the sample were transferred to two sets of plastic tubes and placed in a water bath at 37°C. The Phytase activity was stopped by adding TCA (Trichloroacetic Acid) to the first set of test tubes to act as a control, then, TCA was added to the second set of test tubes after 30 minutes to stop enzyme activity. The test tubes were centrifuged, then, supernatant was transferred to new test tubes, and reagent solutions (ammonium molybdate+ferrous sulfate heptahydrate) were added. The absorbance was measured colorimetrically at 700 nm against the control (Eeckhout and De Paepe 1994). Determination of phy-P and Pi was carried out following the procedures suggested by Raboy and Dickinson (1984), and the result was expressed based on the dry weight.

Statistical Analysis

All the collected data were subjected to analysis of variance using SPSS statistics package, Student Version 18, and means (n= 4) were separated using the Duncan multiple range test at P= 0.05.

RESULTS

Grain Yield

Grain yield was significantly affected by the various levels of NPK fertilization. Application of a high rate of NPK (T_2) resulted in the production of a higher grain yield. It was observed that NPK fertilization, increased grain yield by 151.6% in T_2 and 81. 59% in T_1 compared to T_0 (Table 2).

Grain Minerals Concentration

Statistical analysis of the data showed that the concentrations of grain minerals (N, P, K, Pi, Mg, Zn, and Ca) were highly affected by NPK fertilization (Table 1). Grain minerals were found to be significantly higher in plants supplied with a high dose of NPK (T_2), while the lowest grain mineral content was observed in the control plants

Table 1. Effect of NPK fertilization on the grain minerals content of wheat. [a]

Treatments	N	P	K	Pi	Mg	Zn	Ca
	(mg g^{-1} in dry matter)					(µg g^{-1} in dry matter)	
T_0	16.01[c]	4.04[c]	4.72[b]	0.247[b]	0.132[c]	74.66[b]	71.04[b]
T_1	21.10[b]	4.87[b]	4.89[ab]	0.369[a]	0.143[b]	87.97[a]	107.89[ab]
T_2	26.45[a]	5.41[a]	5.14[a]	0.445[a]	0.158[a]	94.17[a]	188.95[a]

[a] The same letter indicates no significant difference ($p \leq 0.05$). T_0 (control), T_1 (110 kg N + 60 kg P_2O_5 + 55 kg K_2O ha^{-1}), and T_2 (200 kg N + 120 kg P_2O_5 + 100 kg K_2O ha^{-1}).

Table 2. Effect of NPK fertilization on the grain yield and quality of wheat. [a]

Treatments	Grain yield	Starch	Crude protein	Total pentosan	Water-soluble pentosan	Dry gluten	Phytate phosphorus
	(ton ha^{-1})	(%)		(mg g^{-1})		(%)	(mg g^{-1})
T_0	2.77[c]	65.08[a]	8.87[c]	8.58[a]	1.11[b]	3.7[c]	3.14[c]
T_1	5.03[b]	62.98[a]	11.69[bc]	7.75[ab]	1.34[ab]	8.5[b]	3.52[b]
T_2	6.97[a]	63.02[a]	14.66[a]	7.24[b]	1.56[a]	18.9[a]	3.86[a]

[a] The same letter indicates no significant difference ($p \leq 0.05$). T_0 (control), T_1 (110 kg N + 60 kg P_2O_5 + 55 kg K_2O ha^{-1}), and T_2 (200 kg N + 120 kg P_2O_5 + 100 kg K_2O ha^{-1})

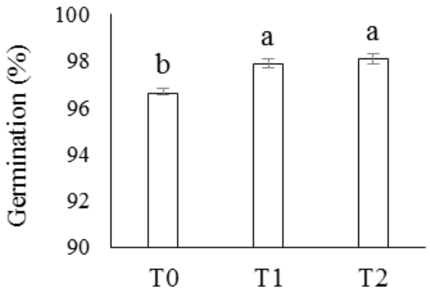
(T_0). A high rate of NPK fertilizers (T_2) increased the concentration of N by 65.2%, P by 33.9%, K by 8.9%, Pi by 80%, Mg by 19.7%, Zn by 26.1%, and Ca by 166.0% compared to the control. Application of a moderate rate of NPK (T_1) increased grain N, P, K, Pi, Mg, Zn, and Ca concentration by 31.79, 20.0, 3.6, 49.39, 8.27, 17.83, and 51.42%, respectively, compared to T_0.

Grain Quality

The result indicated that the grain quality parameters (crude protein, pentosan, gluten) and phy-P content, known as anti-nutrient factor, were highly influenced by NPK fertilization (Table 2). The starch content decreased with an increase in the NPK rate; however, the difference was not statistically significant. The highest crude protein was observed in T_2 plants, followed by T_1; however, the lowest crude protein was recorded in T_0 where no fertilizer was applied. There was a linear increase in the crude protein with an increase in the NPK level. A higher rate of NPK fertilization (T_2) increased the grain crude protein content by 65.3% compared to the control, while a moderate increase of 31.8% in the grain crude protein was observed in T_1 plants compared to the control. Total pentosane was significantly higher in the control plants. With an increased level of NPK, the concentration of total pentosan decreased compared to the control by 15.6 and 9.7% in T_2 and T_1 plants, respectively. Contrarily, water-soluble pentosan was recorded as being higher in T_2 plants. It was observed that NPK fertilization increased the water-soluble pentosan by 40.5% and 20.7% in T_2 and T_1 plants, respectively, compared to the control. The gluten content was significantly influenced by NPK fertilization. There was a linear increase in grain gluten content with an increase in the NPK level. A higher rate of NPK fertilization (T_2) increased the grain gluten content by 5-fold compared to the control, while a moderate increase of 2.3-fold in the grain gluten was observed in T_1 plants compared to the control. The phy-P content was influenced by NPK fertilization. The result obtained from this study indicated that T_2 had a slightly higher grain phy-P content compared to the control.

Effect of Maternal Plant NPK Nutrition

The final count of normal seedlings on the 7th day of germination showed that seedlings which were produced by seeds from T_2 and T_1 plants recorded a higher germination percentage compared to T_0 (Figure 1). The seedling fresh weight was higher in both T_2 and T_1 seedlings over the control on the 7th day of germination. However, T_2 produced a slightly higher fresh weight, but the mean value did not differ from T_1 significantly (Figure 1).



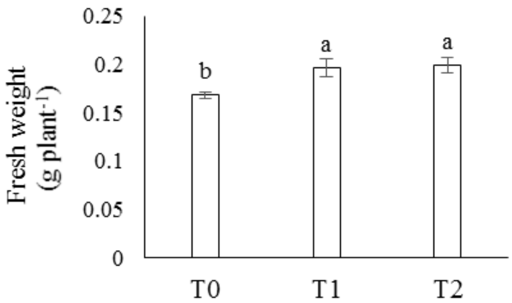


Figure 1. Effect of maternal plant NPK nutrition on the seed germination percentage (left) and fresh weight (right,) of wheat at 7 days after germination. The same letter indicates no significant difference ($P \leq 0.05$).
*T_0 (control), T_1 (110 kg N+60 kg P_2O_5+55 kg K_2O ha^{-1}), and T_2 (200 kg N+120 kg P_2O_5+100 kg K_2O ha^{-1}).

The seed phytase content significantly increased during germination period. A lower phytase activity was recorded in 0-day seeds before germination. The level of phytase activity was highest on the 6th day of germination and the phytase level was recorded as being higher in T_2 and T_1 seedlings compared to T_0 (Figure 2). Germination enhanced the phytase level by 3.22-fold, 3.38-fold, and 4.25-fold in T_2, T_1, and T_0, respectively, on the 6th day of germination compared to 0-day.

The phy-P of the seeds declined during the germination period significantly. The highest phy-P content was recorded in the seeds of T_2, followed by T_1 and T_0 plants before germination (0-day). The lowest phy-P was observed in T_0, followed by T_1 and T_2 seedlings on the 7th day of germination. At the end of the 7th day of germination, the phy-P content decreased by 2.31-fold, 2.34-fold, and 2.43-fold for T_2, T_1, and T_0, compared to 0-day, respectively (Figure 2).

The phytase activity was enhanced during seed germination, and resulted in bioavailability of inorganic Pi. There was a liner increase in Pi with increased time of germination (Figure 3). The highest Pi was recorded in T_2 (2.09 mg g^{-1} dw), followed by T_1 (2.03 mg g^{-1} dw), and T_0 (1.73 mg g^{-1} dw) on the 7th day of germination, while the lowest Pi was observed in T_0 before germination (0-day).

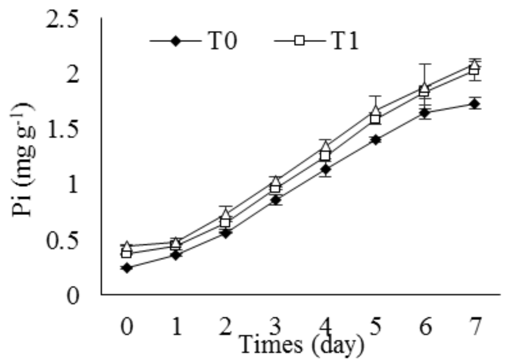


Figure 3. Effect of maternal plant NPK nutrition on the inorganic Phosphorus (Pi) content of wheat during seed germination. * T_0 (control), T_1 (110 kg N + 60 kg P_2O_5 + 55 kg K_2O ha^{-1}), and T_2 (200 kg N + 120 kg P_2O_5 + 100 kg K_2O ha^{-1})

DISCUSSION

The results indicated that combined NPK fertilization increased grain yield and mineral concentration, improved grain quality, and enhanced seed germination and the physiological performance of germinating seedlings. Application of a high rate of NPK (T_2) enhanced plant growth and productivity, and resulted in a higher grain yield. These results are in accordance with Hussain *et al*. (2002), Laghari *et al.* (2010),

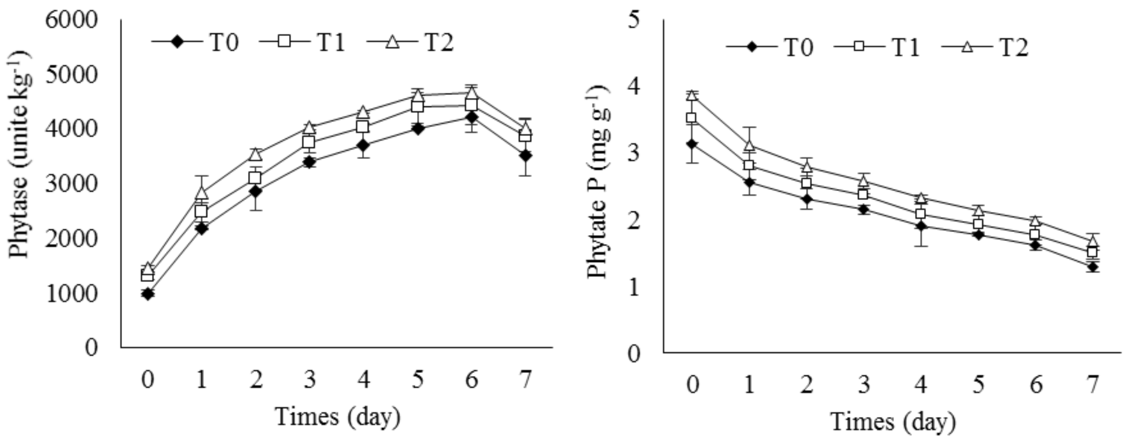


Figure 2. Effect of maternal plant NPK nutrition on the phytase activity (left) and phytate P content (right) of wheat during seed germination. * T_0 (control), T_1 (110 kg N + 60 kg P_2O_5 + 55 kg K_2O ha^{-1}), and T_2 (200 kg N + 120 kg P_2O_5 + 100 kg K_2O ha^{-1})

and Abdel-Aziz *et al*. (2016) who concluded that the grain yield of wheat and cereal crops increased with the application of NPK fertilizers.

The grain mineral concentration was significantly influenced by NPK fertilization. It was observed that the mineral concentration was increased with an increase in NPK rate. Laghari *et al*. (2010) and Campillo *et al*. (2010) concluded that application of N, P, and K enhanced the concentrations of these minerals in wheat. Saha *et al*. (2014) reported that the application of phosphorus fertilizer (single superphosphate) enhanced the total P concentration in wheat grain.

Grain quality, except for starch, was highly influenced by NPK fertilization. The starch content was not affected significantly by NPK fertilization, and a slight decrease in the starch content was observed with an elevated rate of NPK. There is a negative relationship between crude protein and starch content, and N fertilization decreases the starch content of wheat grain (Kindred *et al*., 2008). Crista *et al*. (2012) and Hlisnikovsky and Kunzova (2014) reported similar findings that grain starch was higher in control plants where no fertilizer was applied. NPK fertilization was found to enhance the synthesis of the raw protein in wheat (Crista *et al*., 2012). Sameen *et al*. (2002) found that the crude protein of wheat grain was increased by application of a high level of NPK fertilizers in the wheat variety Inqulab 91. The effect of NPK fertilization on the grain total and water-soluble pentosan content of wheat has not been reported sufficiently in earlier research. However, the influence of ecological environment was found to be significant on the pentosan content of wheat grain (Chunxi *et al*., 2002). Increased pentosan content was found with additional N fertilization under water logging condition in waxy wheat (Jing *et al*., 2010). In this study, total pentosan was decreased with high NPK fertilization, whereas water-soluble pentosan was significantly increased. Courtin and Delcour (2002) reported that water-soluble pentosan had a positive impact on the bread-making quality of wheat, and that water-unextractable pentosan had a negative effect. NPK fertilization significantly influenced the gluten content of wheat flour and the highest gluten was recorded in T_2, where high rate of NPK was applied. Tanacs *et al*. (2005) also found that application of NPK fertilizers significantly increased the gluten content of 4 tested wheat varieties in all 3 years of investigation. Gaj *et al*. (2013) also found that mineral fertilization increased the gluten content of wheat compared to the control, but different levels of P and K did not affect grain gluten significantly.

Phy-P is the major storage form of P in cereals, therefore, the concentration of phy-P mostly depends on grain total P. The phy-P content of many crops was determined by researchers (Garcia-Estepa *et al*., 1999; Rosa *et al*., 1999) but the effect of NPK fertilization on the phy-P content of wheat grain have not been much studied so far. Application of a high rate of P fertilizer might be one of the reasons for high phytate content (Raboy and Dickinson, 1984). In another study, Ali *et al*. (2014) found that application of P increased the grain total P in wheat. Similarly, Laghari *et al*. (2010) revealed that NPK fertilization resulted in a higher P uptake of wheat. Phytase helps phy-P metabolism and Pi bioavailability and activity of this enzyme was increased with NPK fertilization.

Maternal plant NPK nutrition improved the seed germination, seedling growth, and physiological performance. High nutrient reserves in seeds produced by NPK fertilized plants might be the reason for better physiological activity and a high germination percentage in T_2 and T_1 seeds. Seeds of plants which received more fertilizer and irrigation during the production stage can increase seedling establishment in comparison with other treatments (Hampton, 1992). Similarly, Bittman (1989) found that difference in the final germination percentage of seeds could be due to the amount of stored nutrient in the endosperm. Doddagoudar *et al*. (2004)

concluded that application of a higher rate of NPK improved seed quality and resulted in higher seed germination percentage in China aster (*Callistephus chinensis* Nees.L.). During seed germination, the nutrients present in the endosperm are hydrolyzed to guarantee seedling establishment (Shimizu and Mazzafera 2000). In this study, NPK fertilization of the maternal plant improved grain food reserves and helped with a better growth of seedlings and contributed to high seedling fresh weight compared to the control. Phytase activity reached a maximum level on the 6^{th} day of germination, as a result, T_2 and T_1 recorded higher values of phytase. Ma and Shan (2002) reported that seed germination significantly increased phytase activity by 2.04-fold on the 3^{rd} day of germination in wheat. The effect of NPK fertilization on the phytase activity of germinating seeds has not been much studied, and the high phytase level of T_2 and T_1 during the germination period might be due to a high P and protein content in the maternal plant grains compared to the control. Sung *et al*. (2005) revealed that the increase in phytase level may be due to *de novo* synthesis of the enzyme during germination. It was observed in this study that the phytase level started decreasing slightly on the 7^{th} day of germination. The decrease in phytase activity might be due to the degradation of this enzyme by active protease (Houde *et al*., 1990). There was a negative relationship between phytase activity and phy-P content; as phytase activity increased the phy-P content decreased. The effect of NPK fertilization on the seed phytate content during germination has not been studied before. Phytate is degraded by the phytase enzyme during the seed germination of cereals, (Kumar *et al*., 2010). The same trend in the reduction of phy-P content in germinating seeds of cereals has already been reported by other researchers (Azeke *et al*., 2011; Sokrab *et al*., 2012). The Pi content increased during the germination period and it was at maximum on the 7^{th} day of germination. The influence of NPK fertilization on Pi content during seed germination has not been reported. Phytase in germinating seeds removes orthophosphate groups from the inositol ring of phytate to produce free Pi, and a chain of intermediate myo-inositol phosphates (Debnath *et al*., 2005). The increase in the phytase activity of germinating seeds, which coincides with a decrease in the phytate content, may enhance phosphorus availability and utilization (Azeke *et al*., 2011).

CONCLUSIONS

In this study, significant differences ($P\leq 0.05$) were observed in the grain yield, yield component, grain minerals, grain quality, and anti-nutrient content of wheat. A higher rate of NPK (200 kg N+120 kg P_2O_5+100 kg K_2O ha^{-1}) produced high grain yield, and increased the content of grain minerals, crude protein, water-soluble pentosan, and dry gluten, and reduced total pentosan, but did not affect the level of starch in wheat grain. NPK fertilization of the maternal plant enhanced seed germination, seedling growth, and improved the physiological performance of germinating seeds compared to the control. Phytase activity, phy-P degradation, and the release of Pi during seed germination were highly affected by maternal plant NPK fertilization.

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بهبود عملکرد دانه و کیفیت تغذیه ای و ضد تغذیه ای وعملکرد فیزیولوژیکی بذر گندم در اثر کوددهی با NPK

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چکیده

هدف از اجرای این پژوهش مطالعه اثر کوددهی با NPK روی عملکرد دانه گندم، غلظت مواد کانی، کیفیت دانه، گلوتن و محتوای فیتات فسفر(phy-P) و بررسی تاثیر کوددهی گیاهان مادری با NPK روی صفات فیزیولوژیکی بذر در طی جوانه زنی بود. تیمارهای کودی NPK شامل تیمار شاهد (بدون کوددهی)، (T0)، و دو سطح کوددهی (110 kg N + 60 kg P2O5 + 55 kg K2O ha^{-}:(T1) (و ^{1} (T2): (200 kg N + 120 kg P2O5 + 100 kg K2O ha^{-1}) بود. گندم زمستانه این آزمایش در شرایط گلخانه در یک طرح آزمایشی بلوک های کامل تصادفی با ۴ تکرار در فصل زراعی ۲۰۱۵-۱۶ رشد کرد. ازنتایج چنین بر میآید که کوددهی زیادNPK منجر به افزایش عملکرد دانه،پروتئین خام، پنتوسان محلول در آب و گلوتن خشک به ترتیب تا حد 151.6%، 65.3%، 40.5%, و 408.9%در مقایسه با شاهد شد. این کوددهی غلظت کانی های را نیز زیاد کرد ولی برغلظت نشاسته به طور معناداری تاثیر نداشت. مقدار فیتات فسفر(phy-P) در تیمار کودی T2 زیاد شد و جالب بود که در این تیمار مقدار آنزیم فیتاز هم به حد ۴۶٪ بیشتر از شاهد رسید. افزون بر این، کوددهی گیاهان مادری با NPK باعث افزایش جوانه زنی بذر، وزن گیاهچه تازه، فعالیت فیتاز، فسفر معدنی، و متابولیسم phy-P در طی جوانه زنی شد. از نتایج این آزمایش چنین نتیجه گرفته شد که کیفیت غذایی دانه با افزایش مقدار مصرف NPK بهبود یافت ولی ماده ضد تغذیه ای phy-P هم زیاد شد د رحالیکه این ممکن است دوام بذر، جوانه زنی، و قوت گیاهچه را بیشتر کند.