学 位 論 文 の 要 旨

論文題目： **Nutritional and physiological studies on improvement of productivity and grain quality in wheat (*Triticum aestivum* L.) under drought stress condition**

（乾燥ストレス下における小麦の生産性と品質の向上に関する栄養生理学的研究）

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Chapter 1. General introduction

Environmental stress significantly influences crop productivity, and therefore affects food security, availability and quality. Climate change affects precipitation patterns and reduces water availability, which decreases plant growth and yield, and consequently increases food prices. Rainfed wheat faces a problem of water shortages during grain filling period which results in low productivity and yield loss. Many attempts were made to overcome this problem through breeding programs and introducing drought tolerant wheat varieties, however yield loss due to drought stress is still unavoidable. Wheat is a major staple food crop which is consumed largely. Therefore, maintaining grain nutritional quality of wheat is important for human diet. Starch, protein and grain mineral contents are considered as nutritional components of wheat grains, while phytate phosphorus (Phy-P) as an anti-nutrient factor chelates with Ca, Zn, and Fe, and impairs the absorption of these minerals to the human body. Water soluble pentosan (WSP) plays a key role in bread-making quality of wheat flour, it increases the viscosity and the stability of dough foam structure, and it helps in bigger loaf volume and a finer homogeneous bread crumb. The objectives of this study were to examine the effects of nitrogen, phosphorus and potassium (NPK) fertilization, and combined application of salicylic acid (SA) and different levels of K on agronomic performance, productivity, grain mineral, starch, crude protein, total pentosan (TP), WSP, and Phy-P content of wheat under drought stress condition, to enhance wheat productivity and grain quality under drought stress condition.

Chapter 2. Effect of NPK fertilization on grain yield, nutritional and anti-nutritional quality, and seed germination of wheat

In chapter 2, in order to evaluate the effect of NPK fertilization on wheat growth, grain yield, grain minerals content, grain nutritional quality, gluten, TP, WSP, and Phy-P content under normal irrigation (non-stressed) condition, 3 doses of NPK fertilizers: T_1 (control, non-fertilized), T_2 (110 kg N + 60 kg P_2O_5 + 55 kg K_2O ha^{-1}), and T_3 (200 kg N + 120 kg P_2O_5 + 100 kg K_2O ha^{-1}) were applied to the soil, and wheat cultivar Minaminokaori (a common winter wheat cultivar in Japan) was grown

in a vinyl greenhouse. The results indicated that a high level of NPK (T_3) fertilization significantly increased the grain yield (151.6%), crude protein (65.3%), WSP (40.5%), and dry gluten content (408.9%) compared to the control. It also enhanced the grain mineral content, however did not affect significantly the grain starch content. Grain Phy-P was increased with a higher NPK fertilization level, and interestingly the level of phytase that breaks down phytate was also increased up to 46% in the seeds of T_3 treated plants compared to the control. In a laboratory experiment, the effect of mother plant NPK nutrition on seed germination and physiological performance of the second generation was also determined. The results showed that, mother plant NPK fertilization enhanced seed germination percentage, seedling fresh weight, phytase activity, inorganic phosphorus (Pi) content, and Phy-P metabolism of the second generation during the germination period, suggesting that higher grain yield, improvement of grain quality, higher seed germination, improved seedling establishment, and enhancing physiological performance of seedlings of wheat could be achieved with using an appropriate level of NPK fertilization.

Chapter 3. Effect of drought stress and NPK fertilization on grain yield, nutritional and anti-nutritional quality of wheat

To ascertain the effect of combined application of NPK fertilizers on productivity, and grain quality of wheat under drought stress condition, the experiment in chapter 3 was designed with two wheat cultivars (Minaminokaori and Lalmi-2), and 3 levels of NPK fertilizers: F_1 (150 kg N + 100 kg P_2O_5 + 75 kg K_2O ha^{-1}), F_2 (200 kg N + 120 kg P_2O_5 + 100 kg K_2O ha^{-1}), and F_3 (250 kg N + 140 kg P_2O_5 + 125 kg K_2O ha^{-1}). Lalmi-2 is a drought tolerant rainfed wheat cultivar used as a tolerant check in this experiment. Both cultivars were grown in pots in a greenhouse and irrigated regularly until early grain filling stage. Then the plants were exposed to 2 levels of drought stress and well-irrigated control until harvest. The results of this experiment indicated that drought stress significantly decreased grain yield, and grain starch content, but slightly increased grain crude protein, total pentosan, and Phy-P content of both cultivars. Lalmi-2 showed a greater tolerance to drought stress condition exhibiting a higher grain yield, and higher total K and starch content under both well-irrigated and drought stress condition than Minaminokaori. In contrast, Minaminokaori recorded higher value of grain minerals, crude protein, TP, WSP and Phy-P content than Lalmi-2. It is concluded that increase in rate of NPK fertilization could ameliorate the adverse effects of drought stress and enhance plant productivity. At the same time, it may help in increased grain mineral, crude protein and WSP content under drought stress condition. Besides applying higher rates of NPK fertilizers, it is suggested that use of fertilizer responsive and drought-tolerant genotypes such as Lalmi-2 will be beneficial to minimize the risk of yield loss due to drought stress.

Chapter 4. Effect of combined salicylic acid and potassium application on grain yield, nutritional and anti-nutritional quality of wheat under drought stress condition

The study in chapter 4 highlighted the combined effects of SA and K on yield and grain quality of wheat under drought stress condition. Wheat (Minaminokaori cultivar) plants were grown in pots in a greenhouse and subjected to 3 levels of K fertilizer (50, 100 and 200 kg ha^{-1}). The plants were foliar sprayed with SA (0.7mM) at heading stage, and then imposed to the drought stress until harvest. Drought stress decreased grain yield by 41.1%, starch content by 10.2% and WSP content by 3.5% in comparison to well-irrigated control. However, grain crude protein content, TP content and Phy-P content were increased by 33.0, 17.9, and 13.4%, respectively. Under the same drought condition, the application of combined SA and high K levels has increased grain yield (13.3%), starch (12.2%) and

WSP content (20.3%) compared to SA-untreated with low level of K fertilizer treatment. In addition, SA application decreased the percentage of Phy-P to total P under drought stress. These results suggested that combined treatment of SA foliar application and a higher doses of K fertilizer can partially improve wheat productivity and grain nutritional quality, without increasing the anti-nutrient component Phy-P under drought stress condition.

Chapter 5. General discussion

In chapter 5, the results of this study were discussed in the light of recent literature and research findings. It is generally concluded that higher rates of NPK fertilization under normal irrigation condition increase grain yield, grain mineral, crude protein, WSP, and dry gluten contents, however, reduces TP. It did not affect the level of starch content in wheat grain. NPK fertilization of the mother plant enhances seed germination, seedling growth, and improves the physiological performance of the germinating seeds of the second generation compared to the control. Phytase activity, Phy-P degradation, and the release of Pi during seed germination of the second generation was highly affected by mother plant NPK fertilization. Drought stress significantly reduced grain yield, negatively affected grain nutritional quality of wheat by increasing anti-nutrient compound such as grain Phy-P content, and reduced starch content which is the main source of energy. A higher rate of NPK fertilization may effectively attenuate the deleterious effects of drought stress by improving productivity and nutritional quality of wheat under drought stress condition. Comparison of means showed that application of SA and a higher level of K also significantly improved wheat performance, productivity, grain minerals, grain starch, and crude protein content. Considering these observations, both approaches, either applying an adequate level of NPK fertilizers or combined SA and K application can be utilized for minimizing yield loss and improving grain nutritional and bread-making quality in wheat under drought stress condition.