学 位 論 文 の 要 旨

論文題目: **Nutritional and physiological studies on productivity and grain quality of a low-phytate soybean line**
（ダイズ低フィチン系統の生産性および子実品質に関する栄養生理学的研究）

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Chapter 1. General introduction

Phytic acid, known as *myo*-inositol 1,2,3,4,5,6-hexa*kis*phosphate or phytate in its salt form, is present in seeds such as soybean, maize, wheat, and rice. It is a chelating agent for cations and performs the function of P storage, accounting for up to 80% of the total P in seeds. However, phytic acid is poorly digested by monogastric animals such as pigs, chickens, and humans. Phosphorus is an important element in agricultural fertilizers, yet with the worldwide intensification of agricultural production, there are growing concerns about the sustainability of global P supplies. Supplementation of inorganic P (Pi) is necessary to satisfy the nutritional requirements of livestock, but this is a non-renewable, limited resource and we are running out of it. In addition to being poorly digested, dietary phytate chelates divalent cations, reducing the bioavailability and utilization of these essential nutrients. To solve these phytate-related problems, low phytic acid lines of cereals and legumes have been developed. Drought stress and low P levels are the primary abiotic constraints on crop productivity, with the capacity to severely reduce yields and challenge global food security. Drought stress during reproductive stages, especially at the grain-filling stage, result in a substantial reduction in yield. This study investigated the growth, productivity, and seed quality of a low-phytate soybean line compared to a normal-phytate soybean cultivar under drought stress and low P fertilization, and the practicality of low-phytate line was evaluated.

Chapter 2. Effects of phosphorus fertilization on the growth, mineral accumulation, seed yield and seed quality of a low-phytate soybean line

In chapter 2, the effects of P fertilization on the growth, mineral accumulation, seed yield, and seed quality of a low-phytate line compared to a normal-phytate cultivar (Akimaro) from western Japan were evaluated. Two levels of P fertilizers as a single super phosphate (a low P treatment of 20 kg P_2O_5 ha^{-1} and a high P treatment of 100 kg P_2O_5 ha^{-1}) were applied in a randomized complete block (RCB) design with four replicates. The results revealed that P fertilization significantly increased growth, seed yield, yield components, and seed quality of

experimental plants, while the low-phytate line had higher growth, seed yield, yield components, and seed quality than the normal-phytate cultivar under both low P and high P conditions. Minimal differences were observed in total P concentrations of seeds between the low-phytate line and the normal-phytate cultivar, while total P concentrations were higher under the high P treatment. The effect of P fertilization on phytate P and inorganic P concentrations was significant in both the low-phytate line and normal-phytate cultivar. Phytate P concentration in the normal-phytate cultivar was greater than in the low-phytate line under both P fertilization levels. The ratio of phytate P to total P decreased under increasing P fertilization in the low-phytate line; however, it was not greatly affected by P application level in the normal-phytate cultivar. Lipid and protein concentrations of seeds in both the line and the cultivar were significantly higher at the higher P application level. The molar ratios of phytic acid to the minerals iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) were lower in the high P treatment for both the line and the cultivar. In both P treatments, the molar ratios of phytic acid to these minerals were lower in the low-phytate line than in the normal-phytate cultivar, which might increase the bioavailability of the minerals in the low-phytate line.

Chapter 3. Effects of phosphorus fertilization on growth, grain yield and quality of a low-phytate soybean line under drought stress condition

In chapter 3, the effects of P fertilization under drought stress conditions on growth, grain yield, and quality of a low-phytate line compared to normal-phytate cultivar (Enrei) cultivated in western Japan were investigated. Two irrigation levels (control treatment: 85.5 ± 2.4% of the field capacity; drought stress treatment: 35 ± 1.5% of the field capacity) and two levels of P fertilizer (low P treatment: 20 kg P_2O_5 ha^{-1}; high P treatment: 100 kg P_2O_5 ha^{-1}) were applied in a RCB design with four replicates. The drought stress treatment was applied at the grain-filling stage for a total of fifteen days. The results of this study indicated that drought stress and low P treatment significantly reduced seed yield, yield components, and seed quality in both the low-phytate line and the cultivar; however, the reduction was less in the low-phytate line than in the normal-phytate cultivar. Drought stress treatment significantly reduced whole plant dry weight and relative water content in both the line and the cultivar. Phytic acid concentration was significantly lower in the low-phytate line than in the normal-phytate cultivar under drought stress conditions. The molar ratio of phytic acid to minerals in the low-phytate line and the normal-phytate cultivar was significantly less under the drought stress treatment compared to the control for both low P and high P treatments; however, the molar ratio was lower in the low-phytate line than in the normal-phytate cultivar.

Chapter 4. Effects of phosphorus fertilization on dry matter distribution and P translocation in a low-phytate soybean line

In chapter 4, the effects of low P fertilization on dry matter distribution and P translocation were investigated at the vegetative stage in a low-phytate line compared to the normal-phytate cultivar (Enrei). Two levels of P fertilizers (a low P treatment of 25 kg P_2O_5 ha^{-1} and a high P treatment of 100 kg P_2O_5 ha^{-1}) were applied in a RCB design with four replicates. The results showed a significant difference in total dry matter production between low P and high P conditions

in both the low-phytate line and the normal-phytate cultivar. The low-phytate line produced significantly more total dry matter than the normal-phytate cultivar in both P treatments. Under the low P treatment, the ratio of dry matter distribution between lower leaves and upper leaves was lower in the low-phytate line compared to that in the normal-phytate cultivar. Phosphorus concentration and its accumulation in different parts of the plant significantly differed between low P and high P treatments in both the low-phytate line and the normal-phytate cultivar. The translocation of P from lower leaves to upper leaves was more affected by low P treatment in the low-phytate line than in the normal-phytate cultivar. Compared to the normal-phytate cultivar, the low-phytate line showed a higher tolerance to low P treatment and higher accumulation of P in the upper leaves. The low-phytate line had a higher photosynthetic rate, stomatal conductance, and intercellular CO_2 concentration than the normal-phytate cultivar under the low P treatment. This suggests that the low-phytate line is more tolerant to low P conditions and could produce significantly more dry matter overall, allocate more dry matter to the upper leaves, accumulate a greater amount of N and P, and adapt better to low P fertilization than the normal-phytate cultivar.

Chapter 5. General discussion

This study suggests that the low-phytate line achieved greater physiological performance in response to low P fertilization compared to the normal-phytate cultivar. The low-phytate line produced the same or higher seed yield than the normal-phytate cultivar under low P conditions and drought stress conditions. The low-phytate line showed greater nutrient distribution from the lower leaves to the upper leaves than the normal phytate cultivar, which suggests an adaptative mechanism to low P conditions in the low-phytate line might result in a higher translocation ability. The molar ratios of phytic acid to minerals was lower in the low-phytate line than the normal-phytate cultivar under both low P and drought stress conditions, indicating a greater bioavailability of minerals in the low-phytate line. These findings on the characteristics and environmental adaptability of the low-phytate soybean line will pave the way for the practical use of low-phytate lines.