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Soybean Seed Protein Concentration: Current Status and Way Forward

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Declining soybean seed protein concentration – a concern for U.S. soybean industry

Soybean (*Glycine max* [L.] Merr.) is the main source of protein in livestock and poultry feed in the world. Soybean meal, which is a by-product after oil extraction from its seed is used for protein source in most of the poultry and livestock farms in the U.S. and all around the world. The U.S. National Oilseed Processors Association has set a minimum threshold of 44% protein concentration in non-dehulled soybean meal for high quality animal feed to support proper growth and development of poultry and livestock (NOPA, 2024). Soybean seed with 18 - 19% oil concentration (average oil concentration in the U.S. soybean seed) should contain 34 - 35% protein concentration to produce a meal with 44% protein concentration. Soybean yield in the U.S. has gradually increased over the past few decades but consistent decline in seed protein concentration has also occurred during the same period. Average soybean yield in the U.S. was 3412 kg/ha in 2024 after gradually increased from 2241 kg/ha in 1986 (Figure 1). However, in the meantime seed protein concentration has steadily decreased from 35.8% in 1986 to 34% in 2024 (Figure 1). Due to the constant decline in soybean seed protein concentration over the years, soybean meal produced in some U.S. locations is struggling to meet the high-quality animal feed standard. Soybean produced in northern U.S. states contains comparatively less seed protein concentration than southern states. As a result, recent soybean seed produced in some northern states in the U.S. is struggling to produce high quality soybean meal (Chiluwal, 2025). If the trend of declining soybean seed protein concentration continues, it could be a widespread problem across the nation in the future. Therefore, the declining seed protein concentration has become one of the concerns for the U.S. soybean industry. The U. S. is the second largest soybean exporter in the world hence it is important to improve soybean seed protein concentration to make U.S. soybean competitive in the global feed market.

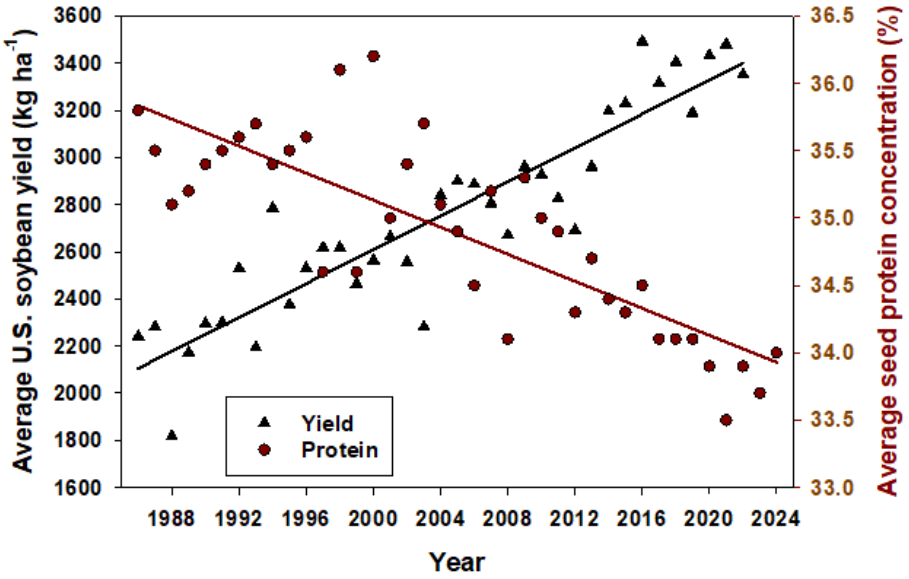

Figure 1: Historical U.S. soybean yield and seed protein concentration between 1986 and 2024 (Data source for the figure: Naeve et al., 2024)

N limitation during seed filling phase - major reason for declining seed protein concentration

Soybean obtains nitrogen (N) from two sources – inorganic N from the soil and organic N from the biological N fixation. Soybean requires a very high dose of N during its seed filling stage. Soil inorganic N will mostly be depleted when soybean reaches seed filling stage and crops rely heavily on biological N fixation. Under the high-yielding environments, only biological nitrogen sources alone may not be able to meet the high N demand during the seed filling phase. As a result, low soybean seed protein concentrations are more common under high yielding environments. Recent studies have shown N limitations during seed filling phase as the major reason for declining soybean seed protein concentration in modern high yielding cultivars (La Menza et al., 2017; Ortez et al., 2018; Chiluwal et al., 2021).

Potential solutions to improve soybean seed protein concentration

Supplemental N during seed filling phase is essential to avoid the N limitations and consequently improve soybean seed protein concentration. Studies have suggested that late season N fertilization (N application after the beginning of seed filling stage) is more effective approach than early season or N application throughout the crop growing season to improve soybean seed protein concentration. Hence, late season N fertilization has emerged as a potential solution to address the declining soybean seed protein concentration trend. However, N fertilization could suppress biological N fixation, which is the most efficient source of N in soybean. Majority of nitrogen needs in soybeans come from biological N fixation (Salvagiotti et al., 2008), hence it is crucial to provide supplemental N fertilizations without negatively affecting its biological N fixation. Studies are undergoing to quantify the effect of late season N fertilization on soybean's biological N fixation and to optimize the late season N fertilizations dose and timing. Hence, late season N fertilizations should be used cautiously as a short-term alternative for now.

Cultural practices such as planting dates, plant density, row types, crop rotation and irrigation determine environmental conditions during crop growth and consequently influence soybean seed composition. Higher temperatures generally decrease soybean seed protein concentration while irrigation and crop rotation improve it. Supplemental bacterial inoculant (N fixing bacteria) application in the seeds or during in-season crop growth has also been tested to improve biological N fixation in soybean. Although it was generally found not effective under normal soybean growing conditions, studies have documented improved N availability to the plants under stressful environments and in the soils with no previous history of soybean cultivation. Soil amendments such as biochar increases root growth, root nodulation and biological N fixation in soybean indicating it could be useful to improve N availability to the plants. Research is undergoing testing the effect of soil amendments on soybean seed composition. Previous studies have made it clear that cultural practices can affect the protein concentration in soybean seeds. Hence, adopting cultural practices which can increase N availability to the plants is another strategy to improve soybean seed protein concentration.

Summary

Nitrogen limitations in high yielding modern U.S. soybean cultivars have resulted in decreased seed protein concentration. As a result, currently produced soybean meal in some U.S. locations is struggling to meet high quality animal feed standard. Supplemental N during seed filing stage is essential to increase soybean seed protein concentration and consequently produce high quality soybean meal for animal feed. Late season N application has emerged as a solution to avoid nitrogen limitation and improve seed protein concentration but its effect on soybean's biological N fixation is still not fully understood. Hence, late season N fertilization should be used cautiously as a short-term alternative. Adopting cultural practices which can increase N availability to soybean is another approach to improve its seed protein concentration.

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