

Review Article

Open Access

Dynamic Changes in Protein and Oil Contents during Soybean Seed Development

Ling Jin ✉

Northwest A&F University, Xianyang, 712100, Shaanxi, China

✉ Corresponding author: 2024012253@nwfu.edu.cnBioscience Methods, 2026, Vol.17, No.5 doi: [10.5376/bm.2026.17.0025](https://doi.org/10.5376/bm.2026.17.0025)

Received: 18 Aug., 2026

Accepted: 22 Sep., 2026

Published: 07 Oct., 2026

Copyright © 2026 Jin, This is an open access article published under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Preferred citation for this article:

Jin L., 2026, Dynamic changes in protein and oil contents during soybean seed development, Bioscience Methods, 17(5): 360-372 (doi: [10.5376/bm.2026.17.0025](https://doi.org/10.5376/bm.2026.17.0025))

Abstract Soybean (*Glycine max* L.) is one of the most important global crops, serving as a primary source of plant-based protein and vegetable oil for food, feed, and industrial applications. The accumulation of storage proteins and oils during seed development is a highly dynamic physiological process regulated by genetic programs, metabolic pathways, and environmental conditions. Understanding the temporal patterns and regulatory mechanisms of protein and oil deposition is essential for improving soybean nutritional quality and optimizing breeding strategies. This review systematically summarizes the dynamic changes in protein and oil contents throughout soybean seed development, with emphasis on developmental stages, physiological regulation, and molecular mechanisms underlying storage compound accumulation. During seed filling, protein accumulation is primarily controlled by nitrogen assimilation, amino acid transport, and storage protein biosynthesis, whereas oil accumulation depends on carbon metabolism, fatty acid synthesis, and triacylglycerol assembly. The interaction between carbon and nitrogen metabolism determines the balance between protein and oil contents, resulting in a complex trade-off relationship that influences soybean quality formation. Furthermore, this review discusses the effects of environmental factors, including temperature, water availability, and nutrient management, on seed composition dynamics. Recent advances in multi-omics technologies, high-throughput phenotyping, and machine learning approaches have provided new insights into the prediction and regulation of soybean seed quality. A case study is presented to illustrate how genotype-environment interactions influence protein and oil accumulation patterns under contrasting cultivation conditions. Finally, future perspectives are proposed, focusing on integrating molecular breeding, precision agriculture, and digital technologies to achieve coordinated improvement of soybean yield, protein content, and oil quality. This comprehensive understanding of dynamic storage compound accumulation provides a theoretical foundation for developing high-quality soybean varieties and sustainable production systems.

Keywords Soybean seed development; Protein accumulation; Oil biosynthesis; Carbon-nitrogen metabolism; Seed quality regulation

1 Introduction

Soybean (*Glycine max* L. Merr.) is one of the world's most important crops because it provides both edible oil and high-quality vegetable protein at a scale that strongly influences global food systems and agricultural markets (Messina, 2022). Its seeds typically contain about 18%-22% oil and 36%-42% protein, making soybean unusual among major crops in combining high energy density with substantial protein yield in a single commodity. This dual value underpins its broad use in human foods, animal feed, and industrial applications, including biodiesel and a wide range of processed products (Hamza et al., 2024). Soybean also occupies a strategic position in efforts to improve the sustainability of protein and oil supply, because demand for vegetable oils and plant-derived proteins continues to rise globally. For these reasons, improving soybean seed composition is not only a breeding objective but also an important challenge for food security, industrial raw material supply, and the design of more efficient crop systems (Duan et al., 2023).

The biological importance of soybean seed protein and oil accumulation lies in their central roles as the principal storage reserves that support germination, early seedling growth, and final seed quality. In mature soybean seed, protein and oil together account for almost 60% of total storage matter, and their composition is closely tied to seed size, nutritional value, and commercial worth (Duan et al., 2023). These reserves do not accumulate