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Soybean: The Future Protein Crop for Global Food Security-How a Modest Legume Became One of the World's Most Consequential Answers to the Protein Question

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Soybean anchors the world's supply of vegetable protein and oil, feeding both livestock and people while fixing much of its own nitrogen. This article traces its nutritional strength, its role in food, feed, and industry, and the climate pressures it faces. Genomic selection, CRISPR editing, speed breeding, and AI are converging to speed up breeding for a warmer, more crowded world.

Keywords: soybean; plant protein; food security; genomic selection; CRISPR; climate resilience

Introduction

Global soybean output hit a record 427 million metric tons in 2024/25, driven by expanded planting in Brazil and the United States (USDA, Foreign Agricultural Service, 2025). A growing, urbanising population is demanding more protein from less land (United Nations, 2015). Soybean answers that demand: it fixes its own nitrogen, rivals meat on protein quality, and processes into everything from tofu to biodiesel.

Soybean: Nature's Protein Factory

Soybean (Glycine max) is a self-pollinating legume domesticated from Glycine soja over several millennia (Hymowitz, 1970). Its seed holds nearly 40 percent protein and 18-20 percent oil, splitting processing into meal and oil streams. Root nodules host nitrogen-fixing Bradyrhizobium, cutting fertiliser need. Its genome, sequenced by Schmutz et al. (2010), is an ancient palaeopolyploid with duplicated genes.

Nutritional Superiority of Soybean

Soy protein isolate scores near 1.0 on the Protein Digestibility-Corrected Amino Acid Score, matching egg and milk protein and beating beef and chicken (Hughes et al., 2011). A newer review found soy products averaging around 85 on the Digestible Indispensable Amino Acid Score, with soymilk scoring highest (van den Berg et al., 2022). Table 1 compares soybean with four rival protein crops.

Table 1. Comparative Nutritional Composition of Major Protein Crops (per 100 g, raw/dry seed)

Crop	Protein (g)	Oil (g)	Carb. (g)	Fibre (g)	Major Advantage
Soybean	36.5	19.9	30.2	9.3	Highest protein density; PDCAAS near 1.0
Chickpea	20.5	6.0	63.0	12.2	High folate; slow-digesting carbohydrate
Lentil	24.6	1.1	63.4	10.7	Very low fat; rich in iron and folate
Pea	25.0	1.2	60.0	26.0	Highest dietary fibre of the group
Groundnut	25.8	49.2	16.1	8.5	Highest energy density; healthy fat ratio

Source: USDA FoodData Central (n.d.); Hughes et al. (2011); van den Berg et al. (2022).

Soybean and Global Food Security

Soybean yields more protein per hectare than most competing crops. As Figure 1 shows, one harvest flows simultaneously into food, feed, and industry, cushioning demand shocks. FAO's latest assessment flags urbanisation and dietary shift as forces pushing global protein demand upward for decades (FAO et al., 2023), and soybean is well placed to meet it.

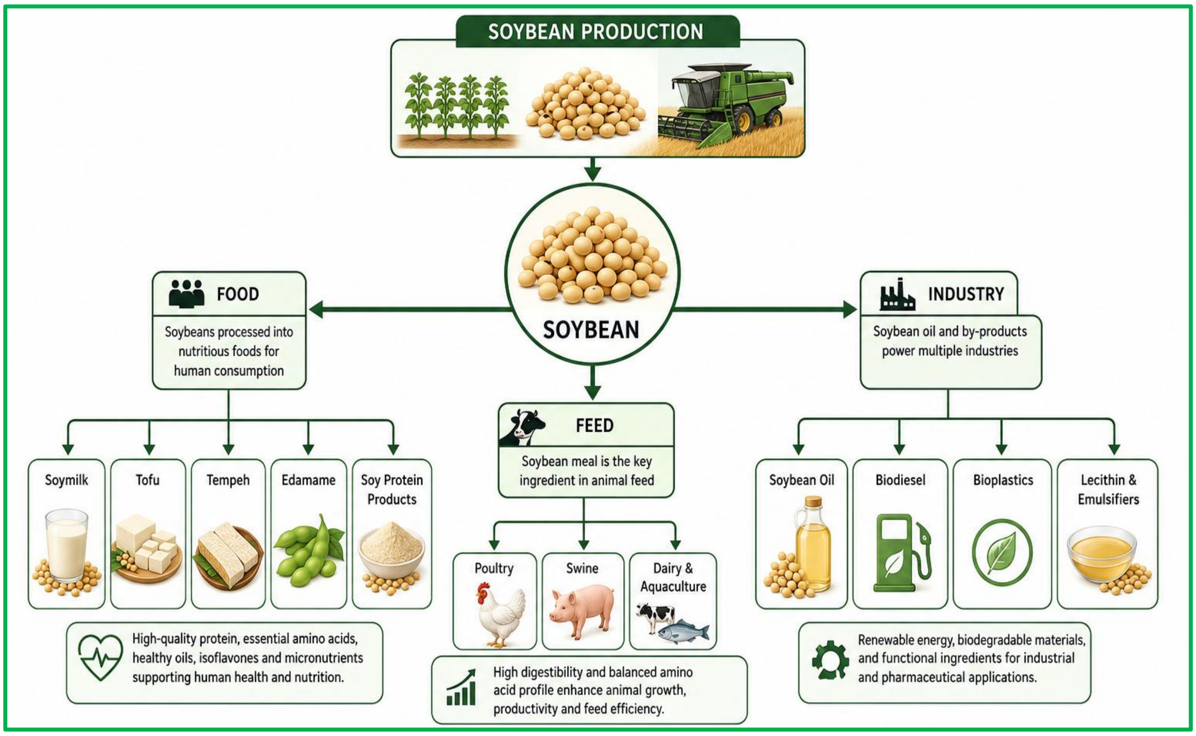

Figure 1: Global soybean production and utilisation pathway.

Environmental and Sustainability Benefits

Nitrogen fixation cuts fertiliser need, but the picture is nuanced: the soybean phase of US maize-soybean rotations contributes about 40 percent of rotation nitrous oxide output; cover crops and later-maturity varieties can cut that by a third (Della Chiesa et al., 2024). Soybean rotations also improve soil structure versus continuous cereals, even as South American land-conversion pressure persists.

Soybean in Human Nutrition

Edamame, soy milk, tofu, and tempeh have moved into mainstream diets, while soy protein isolate anchors functional foods. Soy supplied nearly half of global plant-based meat revenue in 2023, the largest share of any protein source (Grand View Research, 2024). Isoflavone-rich soy foods also draw research interest for cardiovascular and bone-health associations.

Table 2. Major Soybean Producing Countries and Their Global Importance (MY 2024/25)

Country	Production	Major Uses	Strengths	Future Challenges
Brazil	171.5 Mt (~40%)	Crush, export, biodiesel	Near-universal GM adoption; scale	Deforestation; China-export reliance
USA	119.0 Mt (~28%)	Feed, biodiesel, food-grade	Deep genomics/breeding base	Trade exposure; water-limited yields
Argentina	52.0 Mt (~12%)	Meal/oil export, biodiesel	Efficient crushing industry	Currency instability; drought years
China	~20 Mt (top importer)	Tofu, soy milk, feed	Huge domestic demand	Land limits; import dependency
India	~12-13 Mt	Oil, poultry/dairy feed	Growing demand; non-GM niche	Rainfed yields; limited irrigation

Source: USDA, Foreign Agricultural Service (2025); Statista (2025).

Soybean in Animal Feed

Feed is soybean's largest use by volume. Soybean meal anchors poultry and swine rations for its digestibility and lysine-rich profile, a combination few alternatives match at scale (Figure 2). This indirect pathway, feed converted into meat, milk, and eggs, is why soybean's food-security role extends well beyond direct human consumption.

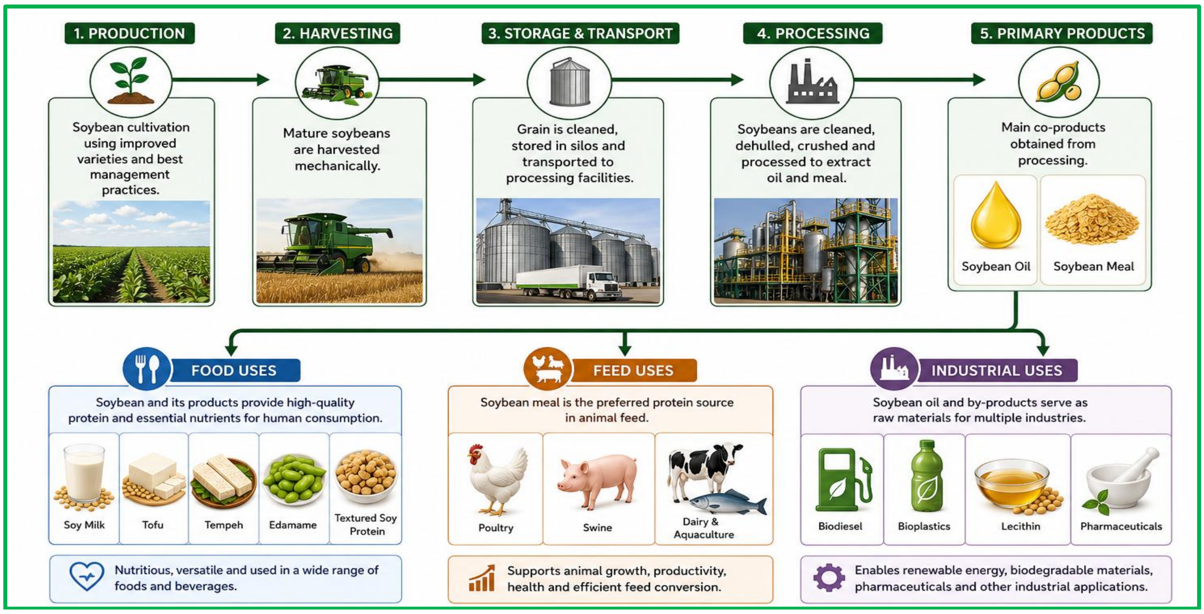

Figure 2: Soybean value chain from field to food, feed, and industry.
(Source: Adapted from USDA and FAO value-chain summaries)

Industrial and Pharmaceutical Uses

Soybean oil and its by-products feed industry: biodiesel in the US and Brazil, bioplastics as petroleum alternatives, and lecithin as an emulsifier and drug-delivery carrier. Isoflavones such as genistein and daidzein remain among the most studied plant bioactives, with continuing research into antioxidant and hormone-modulating effects.

Modern Breeding and Biotechnology

Pan-genome studies beyond Schmutz et al.'s (2010) reference genome reveal major gene-content variation (Li et al., 2014; Torkamaneh et al., 2021). CRISPR editing, first applied to soybean in 2015 (Jacobs et al., 2015), now targets oil quality and transgene-free delivery (Teng, 2024; Yao et al., 2023). Genomic selection (Meuwissen et al., 2001; Miller et al., 2023), speed breeding (Watson et al., 2018; Ghosh et al., 2018), and AI-driven phenotyping (Moreira et al., 2019; Yoosefzadeh-Najafabadi et al., 2021) are converging, as Table 3 shows.

Table 3. Emerging Technologies Driving the Future of Soybean Improvement

Technology	Purpose	Current Applications	Future Potential
CRISPR/Cas editing	Targeted gene modification	High-oleic oil, transgene-free editing (Teng, 2024)	Multiplex-edited, resistant cultivars
Speed breeding	Shorten generation time	Multiple generations/year (Watson et al., 2018)	Automated pipelines with genomic selection
Genomic selection	Predict value from markers	Yield/protein prediction pre-field (Meuwissen et al., 2001)	Climate-tuned ideotypes
High-throughput phenotyping	Rapid trait measurement	UAV/hyperspectral imaging (Moreira et al., 2019)	Autonomous robotic phenotyping
AI / machine learning	Pattern detection across data	Yield prediction from spectral data	AI-guided ideotype design

Source: Watson et al. (2018); Meuwissen et al. (2001); Miller et al. (2023); Moreira et al. (2019); Teng (2024); Yao et al. (2023).

Climate Change and Future Soybean

Elevated CO2 alone tends to raise soybean yield (Ainsworth et al., 2002), but an eight-year field study found this benefit collapses under drought (Gray et al., 2016). Modelling of combined heat, drought, and CO2 stress found yield could fall by up to 91 percent under heat alone. Climate resilience therefore needs separate breeding targets for heat, drought, and seed composition (Figure 3).

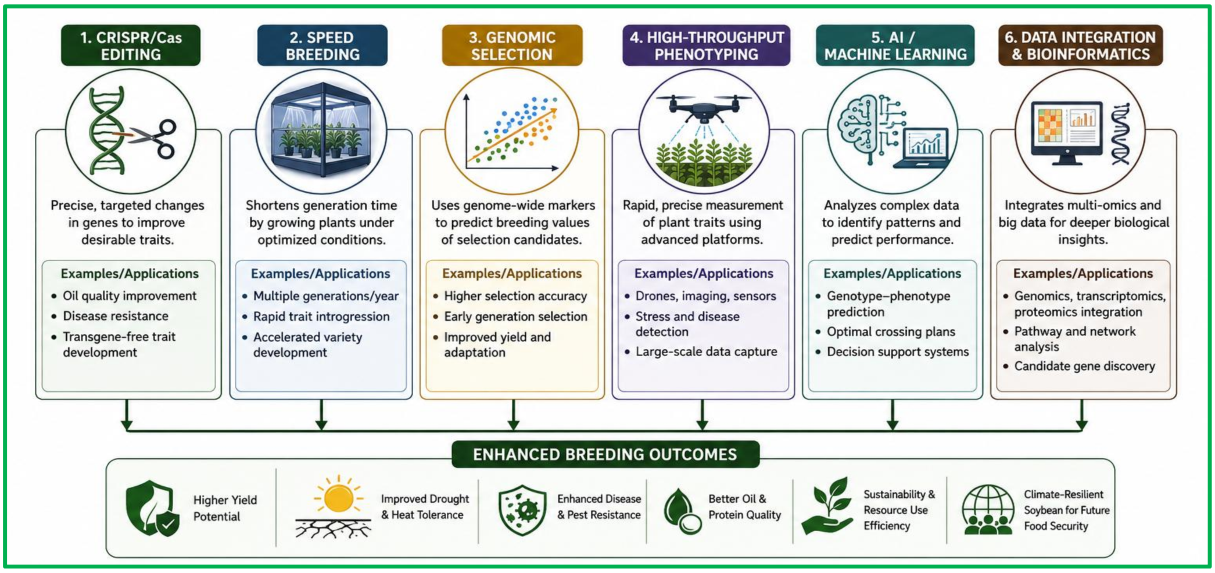

Figure 3: Future breeding technologies converging in soybean improvement.
(Source: Adapted from Watson et al. (2018) and Yao et al. (2023))

Challenges Limiting Soybean Expansion

Brazil, the US, and Argentina supply roughly 80 percent of global output, concentrating market risk. Pests and pathogens, including soybean rust and cyst nematode, continue to erode yield (Hartman et al., 2011). In India, rainfed yields, limited irrigation, and a non-GM system add further constraints; even modern tools need close to a decade to move a trait to release.

Future Outlook

Genomic selection, gene editing, and phenotyping are converging into pipelines where genotyping, prediction, and generation advance within a single season, with AI as the connective layer. Plant-based protein demand's projected double-digit growth through the early 2030s (Grand View Research, 2024) all but guarantees continued investment in soy processing, deepening soybean's food-security role.

Concluding Remarks

Soybean's importance rests on an accumulation of ordinary advantages: protein density, nitrogen self-sufficiency, and processing versatility across food, feed, and industry. Climate stress and slow breeding pipelines remain real constraints, but converging genomic and AI tools make soybean a credible protein crop for the future.

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