Chapter

Soybean Production, Versatility, and Improvement

Zachary Shea, William M. Singer and Bo Zhang

Abstract

Soybean is one of the most widely planted and used legumes in the world due to its valuable seed composition. The many significant agronomic practices that are utilized in soybean production are highlighted with an emphasis on those used during the pregrowing season and growing season. The various pests of soybeans and the pest management strategies used to control them are described with special attention to insects, weeds, bacteria, fungi, and nematodes. The multitude of soybean uses for livestock and human consumption, and its industrial uses are discussed in this chapter. Additionally, the conventional breeding and genetic engineering attempts to improve soybean protein, oil, and sucrose content as well as eliminate the antinutritional factors, such as trypsin inhibitors, raffinose, stachyose, and phytate, are examined. In this chapter, the various management practices, uses, and breeding efforts of soybean will be discussed.

Keywords: agronomic practices, pest management, soybean uses, breeding, genetic engineering

1. Introduction

Soybean (*Glycine max*) is one of the most valuable, versatile, and nutritionally important legumes globally. It can be grown in a multitude of environments, using a variety of management practices, and for diverse end-user purposes. In 2018, roughly 398 million tons of soybeans were produced worldwide which accounted for 61% of overall oilseed production and 6% of the world's arable land use [1–3]. The United States, Brazil, and Argentina constituted approximately 81% of international soybean production, producing 34, 32, and 15%, respectively [4, 5]. Soybean seed composition and its main components, meal and oil, are the driving forces behind crop production that has increased nearly 350% since 1987 [5]. Soybean meal is intricately connected to the food supply through direct food consumption and indirect consumption as a large source of livestock feed. Soy oil provides great versatility with uses in food and beverage, wax, construction, cosmetics, plastics, and fuel.

Soybean originated in East Asia and has been cultivated in China for millennia. It is estimated that the domestication event from wild soybean (*Glycine soja*) occurred during the Shang Dynasty, 1700–1100 B.C. [6]. While no longer the largest producer, China and other Asian countries continue to incorporate large quantities of traditional and innovative soy foods into their diet. In 2018, China was the largest customer for United States whole soybeans, importing over $3 billion worth [7]. The United States and western countries mainly utilize soybean indirectly in the food supply as livestock feed and food ingredients such as textured vegetable protein and protein isolates. However, as more consumers are looking for plant-based protein in their diet, soy foods will become a globally viable alternative to animal protein. As the soybean appetite has increased and transformed, scientific developments have also improved soybean production through agronomic, management, and genetic methods to meet demand.

2. Agronomic practices

2.1 Pregrowing season practices

Soybeans are one of the most flexible crops in terms of production methods, geographical growing regions, and end use versatility. Therefore, there are multiple agronomic practices to consider when preparing a field for soybean production. While tillage and fertilization practices are common among producers, technique specifications can vary greatly due to preferences, environmental conditions, and cost. Historically, mechanized and non-mechanized tillage was considered a vital practice to maximize crop yield and value [8]. While tillage is still a useful tool, contemporary research has corroborated the dangers of over-tilling and the potential benefits from soil conservation and no-till operations. No-till practices and conservation tillage for soybean are wide-spread in areas of highly-erodible soil, and some research has shown that soybean yields remain the same or increase with decreased tillage [9–12]. However, other research has shown that rotational tillage practices will provide higher crop value than no-till practices, specifically because of herbicide costs and equipment requirements [13–15]. Given the need for proper soil maintenance, conservation tillage (<30% crop residue left on the soil surface) is a popular compromise, especially in herbicide tolerant soybean production [16, 17]. Research has further elucidated the benefits of conservation tillage and no-till practices on soil health by showing positive correlations with rhizobia and nematode populations [18, 19].

Pre-plant fertilization for a variety of macro and micronutrients is another common practice in soybean production. Soil fertility programs are designed to provide sufficient nutrients for a crop's needs which maximizes crop yield and farm efficiency while also minimizing environmental impact. To prepare a field for soybean planting, a farmer must start by determining what nutrients are already present in the soil; this can be accomplished by a variety of soil sampling and analysis methods [20]. The primary macronutrients, nitrogen (N), phosphorous (P), and potassium (K), should be examined first alongside critical secondary macronutrients and micronutrients such as sulfur (S), calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn), boron (B), iron (Fe), and copper (Cu). General field nutrient requirement guidelines for soybean production are summarized in **Table 1**. While soybeans require a large amount of nitrogen, fertilization is usually unnecessary because of the symbiotic relationship with *Bradyrhizobium japonicum*,

	N	P_2O_5	K_2O	Ca	Mg	S	Zn	Mn	B	Fe	Cu
kg/ha	275	48	207	113	50	19	0.34	0.37	0.33	0.85	0.06
lb/ac	245	43	185	101	45	17	0.3	0.33	0.29	0.76	0.05

Table 1.
Estimated nutrient uptake and accumulation for 3500 kg/ha^{-1} (52 bu/ac) soybean yield [21–23].

a bacterium that performs nitrogen fixation and provides plant available nitrogen [9, 21, 22]. Depending on field conditions, 25–75% of nitrogen in mature soybeans can originate from symbiotic nitrogen fixation [24]. Excess nitrogen has been linked to negative plant physiological conditions and inhibited rhizobia activity [25]. Thus, the best solution to limited field nitrogen is sometimes soil or seed-applied bacterial inoculation [21, 22, 25]. Soil pH is also a vital component of field management. It is well-documented that all nutrients have varying availability to plants depending on pH [22, 26, 27]. Generally, soybeans prefer a slightly acidic soil ranging from 6 to 7 pH [9, 22]. Liming a field is the optimum technique to raise pH, while the most common practice for lowering pH is elemental sulfur application.

While yield is the driving factor for fertilization, recent market changes have adjusted soybean valuation with increased focus on seed composition quality. Amino acid profiles as descriptors for protein quality in human food and livestock feed as well as high oleic acid soybeans for increased functionality and performance are just two examples of possible premiums producers can receive through soybean seed composition. Research has shown that agronomic practices coupled with location-dependent, environmental variables can directly impact those premiums [28–30]. Nitrogen fertilization plays a limited role in seed composition as it is rarely needed due to the bacterial nitrogen fixation. However, excess nitrogen has been shown to decrease the levels of sulfur-containing amino acids and has an inconsistent effect on fatty acid concentrations [31, 32]. Phosphorous applications can increase protein quantity without adjusting the amino acid profile but also has a positive correlation with higher phytic acid and isoflavone concentrations [33–35]. Additionally, phytic acid has been shown to increase alongside zinc concentrations [33]. Pre-plant potassium applications have limited return on investment in regard to yield and seed composition; however, potassium deficient soybean plants are at a greater risk to insect pests, specifically aphids [36, 37]. Limited yield response is observed with sulfur applications. Although researchers have found the use of sulfur fertilizers to be economically viable, particularly on coarse soils, sulfur fertilization is rarely recommended [9, 21, 38]. Soil sulfur levels have also been shown to greatly impact the ratio between 11S and 7S seed storage proteins [39]. As markets continue to change and value differing soybean seed compositions, it will be critical for producers to fertilize with both yield and seed components in mind.

2.2 Growing season practices

Soybean producers make decisions throughout the year that impact final yield, value, and profit from their annual crop. Many of the most critical decisions occur at the beginning of and throughout the growing season. From the moment a soybean seed is planted to harvest, producers choose (or decide against) a multitude of practices including crop rotation, row spacing, population density, irrigation, post-emergence fertilization, and pest management. Maximizing a potential soybean crop is directly connected to previous field usage. Crop rotation or the process of growing different crops in sequenced seasons within the same field is a common practice in soybean production. Corn (*Zea mays*) and soybean rotations are advantageous because of corn's high nitrogen demand which can be alleviated through *Bradyrhizobium japonicum* nitrogen fixation in soybean nodules. Corn and soybean rotations also exhibit beneficial energy balance and grain yield improvement [13, 40]. Rotations including corn and soybeans as well as wheat (*Triticum*), oats (*Avena sativa*), barley (*Hordeum vulgare*), cotton (*Gossypium*), and forageable pasture have also shown potential for economic and environmental gains [22, 41, 42]. Although depending on crop sequences, new management practices may be needed. For example, alfalfa or clover following soybeans would require liming for maximum production as those crops prefer a slightly higher pH [43].

Protecting and revitalizing the soil through non-harvested crops planted between soybean growing seasons or cover cropping is also beneficial. Cover crops protect the soil that would otherwise be farrow and replenish nutrients assimilated into the soybean plant [9, 22, 43]. Furthermore, cover crops can beneficially reduce weed pressure, lessen soil compaction, and improve water conservation [44–46]. However, cover crops increase annual cost and have not been shown to increase soybean yield which can negatively impact certain producer's net profit [47]. Many farmers who receive enough growing degree units throughout the year also limit farrow fields by double cropping with soybean. Soybean and wheat double crop systems have exhibited high economic returns for producers in both field and modeling research [48, 49]. Double cropped soybeans exhibit lower yield due to late planting and decreased leaf-area-index potential, but this can be mitigated with early maturing varieties [50, 51]. Intercropping or growing at least two crops simultaneously is another, less-common option for soybean production. Corn and soybean intercropping can increase yields for both crops with the proper seeding rates [52, 53]. Wheat and soybean intercropping also displays positive yield response [54, 55]. Sugarcane (*Saccharum officinarum*) and soybean interspecific relationships increase sugarcane yield and improves rhizospheric activity while reducing soybean yield [56]. While intercropping can enhance value for soybean producers, it is unsuitable for most large-scale production systems.

After choosing a cropping system, soybean producers must then determine the proper row spacing and population density for their environment. The appropriate balance between row space and plant density is critical for maximum soybean production and reliable economic returns. Narrow rows and high plant densities both correlate with quickened canopy closure and weed suppression [57–60]. Increased plants per field also increase cost; however, subsequent increased yield and profit overcomes the cost [61–63]. As soybeans emerge and grow, the next consideration for producers is irrigation. This localized decision can be based upon historical precipitation records, predicted forecasts, day-to-day weather events, or a combination of factors. In the absence of natural precipitation, irrigation is vital to soybean production as water deficiencies inhibit yield potential [64–67]. Irrigation can also be optimized spatially throughout a field with variable rate techniques and temporally across the growing season by targeting specific growth stages [68, 69]. Fertigation applications can be used to combine applications of post-emergent fertilizer with irrigation. Other methods of post-emergent fertilization including foliar spray and direct-to-soil applications are more common solutions for growing season nutrient issues. Plant tissue sampling and analysis can be coupled with soil samples to determine in-season soil deficiencies and to prescribe further applications [9, 21, 26]. As soybean increases nitrogen uptake during reproductive stages when bacterial fixation may be diminishing, soil or foliar nitrogen applications are typical yet usually ineffective. While limited yield increases can be seen from supplemental nitrogen applications or various nutrient combinations, the economic returns generally fail to cover the cost of application [70–73]. Foliar nutrient applications have shown minor impacts on seed protein and oil content; however, these results are inconsistent amongst experiments [74, 75]. A location-specific, comprehensive nutrient management plan that accounts for all other agronomic practices is the best method for maximizing yield and economic returns in soybean production.

3. Pest management

3.1 Insect pests

Insect and insect-like pests of soybean vary greatly ranging from aphids to stinkbugs to loopers to beetles. Which insects are the major pests and potential pest impact on soybean varies significantly from year to year and depends on the region the soybean crop is grown. Total damage by insects is a little ambiguous but yield losses of up to 80% have been reported [76]. Some prominent insect pests include soybean aphids (*Aphis glycines*), Japanese beetle (*Popillia japonica* Newman), Mexican bean beetle (*Epilachna varivestis* Mulsant), two-spotted spider mites (*Tetranychus urticae*), brown marmorated and red banded stinkbug (*Halyomorpha halys* and *Piezodorous guildinii*), bean leaf beetle (*Cerotoma trifurcata*), and kudzu bug (*Megacopta cribraria* Fabricius) [76–81].

Insecticides constitute a large portion of insect management as they are used to control most insect pests and in some cases are the primary method of control [80]. Integrated pest management (IPM) is becoming more common among growers due to its ability to reduce pesticide use, non-pests affected, workers' exposure to pesticides, and the likelihood insecticide resistance [82, 83]. Additionally, it has been found to be effective at reducing damage done by pests equivalent to conventional methods [84]. IPM works similarly for all pests. It involves monitoring fields to determine which pests are present, determining which pesticides can and should be used, and incorporating cultural management practices [83]. For insects, trap cropping and sweep nets are used to monitor and determine which insect pests are present [85, 86]. The cultural practices used in insect management include altering planting date and row spacing, using no-till fields, and using resistant soybean cultivars [76–81].

3.2 Weeds

Weeds are considered one of the most damaging, if not the most damaging pests, in soybean [87]. About 37% of global production of soybean is affected by soybean, while 23% of global production is affected by other pests [88]. In the United States alone, it has caused losses of several million US dollars each year [87]. Weeds pose a problem for soybean crops since they compete for nutrients, space, and other resources [89]. There are many different weed pests that compete with soybean, some of which include common waterhemp (*Amaranthus rudis*), Canadian horseweed (*Conyza canadensis*), giant ragweed (*Ambrosia trifida*), ivy-leaf morning glory (*Ipomea hederacea*), common cocklebur (*Xanthium strumarium*), Johnsongrass (*Sorghum halepense*), and pigweed (*Amaranthus* spp.) [90, 91]. It is important to note that which weeds are found in a particular field depends largely on where the soybean crops are grown.

Management of weeds is largely done through integrated pest management. This involves using herbicides along with herbicide resistant soybean varieties and cultural practices [87, 92]. There are many different classes of herbicides that include enzyme inhibitors, lipid synthesis inhibitors, photosystems diverters, nucleic acid inhibitors, and auxin inhibitors [93]. Historically, herbicides have been a large part of weed management and will most likely remain significant due to effectiveness and limited efficiency through other individual methods [87]. Furthermore, herbicide effectiveness can be improved by using herbicide resistant soybean, such as glyphosate resistant Roundup Ready soybean. Although since weeds can develop resistance to herbicides, it is important to incorporate other management practices [87]. One such method is herbicide spray timing. A common management practice involves pre- and postemergence herbicide applications. This involves spraying herbicides before and a few days after the soybean plants have emerged to reduce any damage to the soybean plants [94]. Additionally, cultural control practices are used including crop rotations, planting in narrow rows and proper fertilization to promote crop competition, and cultivation [92]. Crop rotations allow for different herbicides to be used which in turn helps to prevent the development of herbicide resistant weeds [92]. Promoting crop competition through planting density allows soybean plants to grow enough to create a canopy to maximize shading of weeds [92]. Cultivation is an effective and economical way to control weeds to help minimize herbicide use [92]. All of the aforementioned management practices are parts of integrated weed management and will continue to play a significant role in control of weeds.

3.3 Diseases

Similar to the insect pests, there is a wide variety of diseases in soybean. Most diseases are caused by fungal and bacterial diseases and can be vectored by nematodes. Fungal diseases have been known to reduce yield up to 50%, while bacterial diseases have been known to cause yield loss of anywhere between 15 and 60% [76]. Which disease is the most devastating depends on the region and the year, but the most prevalent diseases include *Heterodera glycines*, *Phytophthora sojae*, *Colletotrichum truncatum*, *Septoria glycines*, and *Phakopsora pachyrhizi* [76]. Of these five diseases, *Heterodera glycines*, or soybean cyst nematode is the most economic damaging disease being found in all countries that grow soybean and causing up to 90% yield reduction in some areas [76]. **Table 2** provides an overview of some of the main soybean diseases.

From **Table 2**, it is evident that chemical pesticides still play a large role in treatment strategies against all major diseases in soybean. However, there has been a rising interest to incorporate other methods that prevent and treat diseases in soybean due to the harmful environmental and health effects of pesticides. Some other methods to control soybean diseases are seen in cultural control practices, such as increasing or decreasing tillage and crop rotation, drainage, and using resistant cultivars [103]. While the treatments listed in the above table are usually effective, there is continual research to find innovative ways to improve the control of plant diseases. One such example is the development of using hyperspectral bands for early detection of charcoal rot in soybean [104]. These researchers developed a method that involves analyzing spectral and spatial information of infected and healthy soybean in order to find wavebands that signify a soybean plant that is infected with charcoal rot [104]. This process identified six wavebands that were specific to plants infected with charcoal rot and can potentially allow for the detection of charcoal rot in crops in three days [104]. By being able to identify disease earlier, growers can minimize the damage done by that disease by removing infected plants and incorporating treatment strategies, such as pesticides or cultural controls.

The research above shows that there is interest in developing early detection for soybean pathogens. One of the other major areas of research for soybean diseases, is identifying resistance genes to promote resistant cultivars. Given that soybean cyst nematode is one of the most devastating soybean diseases there has been a lot of research done to identify genes involved with resistance to soybean cyst nematode. The main resistance gene in soybean to cyst nematode is the Rhg1 gene, which encodes an amino acid transporter [105, 106]. This gene confers partial resistance and has been shown to reduce reproduction of soybean cyst nematode and improve yield in fields that are infected with soybean cyst nematode [78]. Even though there are resistant cultivars available, they do not permanently stop diseases. For soybean cyst nematode, it is advised to utilize cultural practices, such as using multiple resistant cultivars and rotating with non-host crops that are resistant to cyst nematode, and other methods [107]. This is a classic example of how integrated pest management involves continuously incorporating new methods to control diseases to prevent the disease from overcoming any pesticides and resistant cultivars.

Name	Type	Causal Agent	Transmission	Symptoms	Treatments
Charcoal rot	Fungal	*Macrophomina phaseolina*	Soil born	Wilting, necrosis, black/dusty microsclerotia on stem/pods/seeds, brown lesions on emerged seedlings	Fungicides, resistant cultivars, reduce tillage, crop rotations
Soybean Cyst Nematode	Nematode	*Heterodera glycines*	Soil born	Stunted roots, can increase sensitivity to some fungal diseases, presence of cysts on roots	Resistant cultivars, crop rotations
Phytophthora Root and Stem Rot	Oomycete	*Phytophthora sojae*	Can overwinter in soil, water	Reddish-brown/black lesions on stem, chlorotic leaves, soft rot on roots, seed rot, emergence damping off of seedlings	Seed treated fungicides, improving soil drainage, resistant cultivars
Soybean Bacterial Blight	Bacterial	*Pseudomonas syringae pv. glycinea*	Water, can overwinter in plant residue	Affects mid to upper leaves, yellowish-brown, angular lesions on leaves, discolored/shriveled seeds, water soaking	Copper fungicides, resistant cultivars, increasing tillage, crop rotations
Soybean Anthracnose	Fungal	*Colletotrichum spp*	Seedborn, can overwinter in plant residue	Brown lesions with setae, pods with fewer seed, brown cankers, defoliation, damping off	Crop rotation, fungicide treated seed
Brown spot/ Septoria Brown Spot	Fungal	*Septoria glycines*	Can be transmitted through infected seed, can overwinter in plant residue	Small, brown lesions on leaves, yellowing leaves, lesions contain pycnidia	Foliar fungicides, crop rotation, increased tillage
Soybean Rust	Fungal	*Phakospora pachyrhizi*	Spores are spread by wind	Reddish/brown lesions with pustules on leaves, pods, and seeds	Fungicides

Table 2.
Overview of 7 prevalent diseases in soybean [95–102].

4. Soybean utilization and products

4.1 Livestock feed

Soybean is a valuable crop worldwide mainly because of soybean meal's nutritional efficacy as a food and feed ingredient. A high protein content, balanced essential amino acid profile, and the presence of other beneficial nutrients all contribute to its economic and nutritional value. Soybean meal constitutes 70% of seed value while only being roughly 35% of seed dry weight [108, 109]. Furthermore, in the United States, 97% of soybean meal is used for livestock feed [109]. This overwhelming usage rate as a livestock protein source is mainly due to the presence of essential amino acids. While some livestock require other amino acids, most livestock need nine essential amino acids: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine [110]. All nine of these amino acids are found in some quantity in soybean meal [111]. For this reason, soybean meal can maximize livestock production in cattle, swine, poultry, and aquaculture. Generally, soybean meal and other soy byproducts use are limited to a supplementary or finishing role for cattle due to feed ration complications from other seed components [110, 112, 113]. Soybean meal use is highly prevalent in monogastric livestock production such as swine and poultry and is increasing in popularity for aquaculture [114, 115]. However, soybean as feed has two main obstacles: methionine deficiency and trypsin inhibitor proteins. Albeit present in soybean, methionine content is deficient for livestock needs, is considered the first limiting amino acid for soybean meal and requires producers to supplement with synthetic methionine [116–120]. This has a variety of negative economic and environmental impacts, including increased cost and poor nitrogen-use efficiency [121, 122]. Trypsin inhibitor proteins are an antinutritional factor present in raw soybean that decreases feed efficiency and can harm the livestock. There are a variety of industrial processing methods used to overcome trypsin inhibitors in soybean such as thermal and infrared treatment [123]. In the future, soybean methionine deficiencies and trypsin inhibitor levels may both be solved via breeding and transgenic efforts.

4.2 Human food

Soybean as human food exists to two different extents that are derived from geography and cultural tradition. Eastern hemisphere populations incorporate whole soybeans and processed soy foods into their lives on a daily basis, whereas Western hemisphere populations generally utilize processed soybeans as food ingredients. Eastern soy foods are divided into two main categories: fermented and non-fermented. Non-fermented soy foods include whole seed options such as whole dry soybeans, soy nuts, and edamame, processed items such as soy flour and soy milk, and vegetative soy sprouts [115, 124]. Soy milk in its simplest form is a water extract from soybean that when further processed can make tofu and tofu byproducts such as okara (soy pulp) and yuba (tofu skin). Fermented soy products include miso, soy sauce, tempeh, natto, and sufu, and each product has a specific bacterial species that enables proper fermentation. For example, natto is associated with Bacillus subtilis, and soy sauce is associated with Aspergillus sp. [115, 124]. Western cultures have assimilated many soy food products, and they are becoming more popular as consumers seek plant-based protein sources. However, the vast majority of soybeans in western diets consists of food ingredients made from soybean meal and soy oil. Soybean meal can be processed into ingredients such as soy flour, protein concentrates, and protein isolates that are used in bakery mixes, breakfast cereals, baby food, and exercise supplements [114]. Soybean oil is widely used in vegetable oil and margarine mixes for a variety of cooking purposes. The importance of traditional and innovative soy food uses has perpetuated because of the potential health benefits from soy consumption. Soy foods have been shown to play a role in chronic human disease prevention for conditions such as heart disease, osteoporosis, and cancer [125–127]. However, isoflavones, one of the most common seed components linked to disease prevention, is also negatively linked to hormonal health as a phytoestrogen. While large population subsets are concerned about isoflavones negatively impacting fertility, summarized data has shown inconsistent results [128–130]. As consumers continue to seek plant-based protein, soybeans will be the premier source for historically and culturally significant recipes as well as healthy, novel animal meat alternatives.

4.3 Industrial uses

Even though soybean is classified as an oilseed, soybean oil has historically been an afterthought for soybean producers and processors. When markets for soybean meal would falter, researchers and other stakeholders would turn to soybean oil for added value or seek alternative uses for meal components. Modern sustainability and industrial goals have stimulated soy-based product usage in a variety of fields, as summarized in **Table 3**. Soybean oil as biodiesel has experienced the largest

Soybean Oils		Soybean Lecithin	Soybean Powders
Anti-static agents	Lubricants	Alcohol	Adhesives
Candles	Metal casting	Concrete	Antibiotics
Caulks	Oiled fabrics	Inks	Asphalt
Concrete	Paints	Magnetic tapes	Fermentation aids
Crayons	Pesticides	Paint	Packing films
Dust control agents	Plastics	Paper	Firefighting foams
Electrical insulation	Printing inks	Pesticides	Inks
Epoxy	Putty	Pharmaceuticals	Leather substitutes
Fatty acids	Soaps and detergents	Synthetic rubber	Particle boards
Fatty alcohols	Solvents	Softening leather	Pesticides
Fuel	Vinyl	Yeast	Pharmaceuticals
Hydraulic fluids	Wallboard		Plastics
Pesticides			Polyester
Linoleum backing			Textiles

Table 3.
Industrial uses for soybean products [114, 115].

growth with United States consumers using over 2 billion gallons in 2017 [131]. Current biodiesel production methods can create soy-based fuel that perform nearly equal or equivalent to standard diesel fuels and have the potential to become a truly renewable resource when coupled with sustainable farming practices [132–134]. Constantly improving processing methods will continue to augment soybean seed component versatility and create new opportunities for soy-based products.

5. Soybean seed composition improvement

5.1 Breeding efforts

Soybean seed has many beneficial traits, such as high protein, oil, and soluble sugar content [135]. While soybean seed value is defined by these favorable qualities, past and present breeding attempts have sought further improvement. With regards to protein content, breeders have worked with soybean to increase total protein content as well as the amount of sulfur containing amino acids, methionine and cysteine [135]. Methionine and cysteine are of interest since the seed protein is naturally deficient, and these two amino acids can improve the nutritional value of soybean meal [135, 136]. However, some research indicates that total protein content is negatively correlated with other favorable seed qualities, including yield, oil content, and potentially methionine and cysteine content [137, 138]. So far, most breeding efforts to improve protein quality have involved identifying quantitative trait loci (QTL) that are associated with the amino acid content [139]. QTLs are regions of DNA that are associated with a particular trait and allow breeders to select for particular cultivars that have the trait of interest [140]. The composition of soybean seed oil primarily includes linolenic, steric, palmitic, linoleic, and oleic acid [141]. There have been breeding attempts mainly to increase oleic acid in soybean seed while keeping linolenic acid relatively low, due to respective human health impacts [141, 142]. Lastly, soluble sugar levels, specifically sucrose content, has also been an area of interest in soybean breeding [135]. While sucrose is the main sugar found in soybean, fructose and glucose are also present but in trace amounts [143]. Similar to protein content, multiple QTLs have been identified associated with high sucrose [144]. Sucrose is a desirable seed composition trait due to soy food flavor improvement for human consumption [144]. Overall, conventional breeding has been used to improve protein quality, oil content, and sucrose content in soybean seed.

While soybean does have numerous profitable seed traits, it also contains several unfavorable traits that include trypsin inhibitors (TIs), indigestible carbohydrates, and phytate [145, 146]. There are two trypsin inhibitors found in soybean, the Kunitz and Bowman-Birk trypsin inhibitor, and they are antinutritional factors due to their ability to interfere with protein digestibility and reduce the health of animals that are fed soybean meal containing these proteins [147, 148]. Currently, processors can heat the soybean meal in order to inactivate the trypsin inhibitors, but this step is costly [149]. Due to TIs negatively affecting animal health and increased cost for inactivation, more breeding efforts are being made to develop low-TI soybean lines [150]. Indigestible carbohydrates, raffinose and stachyose, that are found in soybean seed are also a target for soybean breeding since they can cause flatulence and diarrhea when consumed [144]. There has been progress made in lowering these carbohydrates, which include identifying QTLs associated with raffinose and stachyose [144]. Lastly, while phytate is an antinutritional factor found in soybean, there is not a lot of work being done anymore to breed low phytate soybean lines since phytase supplements are an effective, inexpensive way to reduce the phytate found in soybean meal [151].

5.2 Genetic engineering efforts

Genetic engineering involves the process of artificially and intentionally manipulating the DNA of an organism with the purpose of modifying that organism [152]. Some of the methods used to transform plants include *Agrobacterium*, electroporating plant protoplasts, and microparticle bombardment [153]. One relatively new field within genetic engineering is gene editing which involves using clustered regularly interspaced short palindromic repeats or CRISPR/Cas9 system [154]. Genetic engineering works by introducing a gene from one organism into another organism so that it can now express that gene product or by causing frameshifts or deletions to knockout a particular gene in an organism [152]. CRISPR/Cas9 has been gaining a lot of attention due to its promising ability to efficiently and effectively improve agronomic traits in crops [155, 156]. Genetic engineering in soybean was first successfully accomplished in the 1990s [157]. Since this time, genetic engineering has been used frequently in soybean with about 90.7 million hectares of genetically modified/GM soybean being planted in 2014 [157]. Most of this genetic engineering has been done to create Roundup Ready soybean that is resistant to glyphosate herbicides [158]. Roundup Ready soybean is prevalent because it allows growers to spray herbicides to kill any weeds in the field while not killing the soybean [158]. Genetic engineering has been used to additionally improve the protein quality of soybean by altering biosynthetic feedback pathways to increase lysine and by expressing zein proteins from corn to increase sulfur containing amino acids [115, 159]. Besides these examples, genetic engineering has been used to manipulate soybean oil content by increasing oleic acid content and decreasing linolenic acid content and to delay flowering time in soybean [160, 161]. Given the ability of genetic engineering, especially gene editing, to successfully improve qualities of soybean, it will likely be used to improve soybean through removing and/or modifying expression of antinutritional factors. This can be accomplished through genetic engineering by knocking out particular genes responsible for the antinutritional factors preventing them from being expressed.

6. Conclusions

Soybean is an essential crop that is grown globally due to its various and diverse uses. Given its importance, there are many pre-growing practices to prepare the field for the growing season, including tillage, pre-plant fertilization, and monitoring soil pH. Many agronomic aspects must be considered during growing season to ensure successful soybean growth including crop rotations, double cropping, cover crops, irrigation, row spacing, plant density, and post-emergence fertilization. Additionally, integrated pest management involving the use of pesticides, resistant soybean cultivars, and cultural practices are vital to control the numerous pests of soybean. While soybean is highly used in livestock feed due to its high protein content, it's methionine deficiency and presence of antinutritional factors still present problems that need to be solved. Soybean versatility is represented by the many uses in human consumption, biofuels, and other industrial uses. Traditional and conventional breeders have been working to increase protein and oil content, while eliminating antinutritional factors. Genetic engineering and gene editing show promise to help improve soybean by introducing genes to improve protein and oil quality and knocking out genes to remove antinutritional factors.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Zachary Shea*, William M. Singer and Bo Zhang
School of Plant and Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

*Address all correspondence to: zacharys@vt.edu

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