1 Soybean

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1.1 Introduction

Soybean [*Glycine max* (L.) Merr.], grown for its edible seed protein and oil, is often called the miracle crop because of its many uses. Seed composition averages 40% protein, 20% oil, 35% carbohydrate, and 5% ash on a dry-weight basis (Liu 1997). Each component is affected by the growing environment and varies among soybean genotypes (Fig. 1). A 50-kg bag of soybeans yields about 40 kg of protein-rich meal and 9 kg of oil.

The expansion in world soybean production and the increasing importance of soybeans as a world crop are great (http://www.soystats.com). Soybean is now an essential and dominant source of protein and oil with numerous uses in feed, food, and industrial applications (Table 1). It is the world's primary source of vegetable oil (Fig. 2) and protein feed supplement for livestock (Fig. 3). Recent nutritional studies claim that consumption of soybean reduces cancer, blood serum cholesterol, osteoporosis, and heart disease (Birt et al. 2004). It has sparked increased demand for the many edible soybean products (Table 1). The priority for more meat in diets among the world's population has also increased the demand for soybean protein for livestock and poultry feed. In addition to feed and food, soybean has numerous industrial applications (Table 1) such as building materials, plastics, printing inks, paints, hydraulic fluids, cosmetics, pharmaceuticals, and soy diesel fuel that burns cleaner and pollutes less than petroleum-derived fuels.

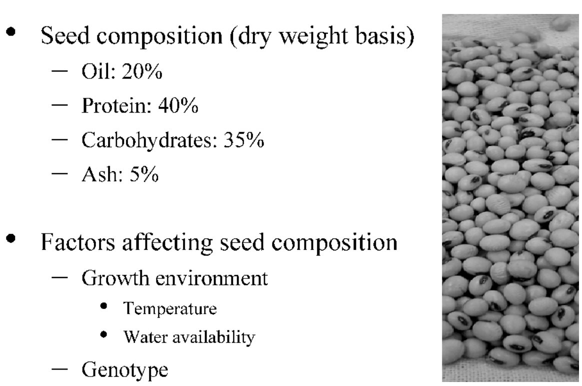

Fig. 1. Composition of soybean seed (Liu 1997) and major factors affecting seed composition

World production of soybeans has tripled in the last 20 years (www.soystats.com), rising from about 70 million metric tons to over 200 million metric tons (Fig. 4). The soybean plant is bushy and green and is a legume related to clover, peas, and alfalfa. Soybean has a different seed composition than other legumes in that it is high in both protein and fat with little carbohydrate content. Soybean protein is well balanced compared to other protein sources. The oil portion of the seed is composed primarily of five fatty acids. Palmitic and stearic acids are saturated fatty acids and comprise 15% of the oil. Soybean is rich in the unsaturated fatty acids, oleic, linoleic, and linolenic which make up 85% of the oil. Soybeans are a good source of minerals, B vitamins, folic acid, and isoflavones, which are credited with slowing cancer development, heart disease, and osteoporosis (Wilson 2004).

Soybean products have long been consumed by humans in various forms for its protein in China and parts of eastern and southern Asia. The center of origin of soybean is China, and domestication probably took place about 3000 to 1500 BC. From northern and southern China,

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Table 1. Uses of soybean (Source: The American Soybean Association; www.soygrowers.com)

WHOLE SOYBEAN PRODUCTS	OIL PRODUCTS				SOYBEAN PROTEIN PRODUCTS
	Glycerol, sterols, fatty acids	Refined soyoil	Soybean lecithin	Soy flour concentrates and isolates	Soybean meal
EDIBLE USES	Oleochemistry	**EDIBLE USES**	**EDIBLE USES**	**EDIBLE USES**	**FEED USES**
Seed	Soy diesel	Coffee creamers	**Emulsifying agent**	Alimentary pastes	Aquaculture
Stock feed	Solvents	Cooking oils	Bakery products	Baby food	Bee foods
Soy sprouts		Filled milks	Candy/chocolate	Bakery ingredients	Calf milk replacer
Baked soybeans		Margarine	Coatings	Candy products	Fish food
Full fat soy flour		Mayonnaise	Pharmaceuticals	Cereals	Fox and mink feed
Bread		Medicinals		Diet food products	Livestock feeds
Candy		Pharmaceuticals	**Nutritional uses**	Food drinks	Poultry feeds
Doughnut mix		Salad dressings	Dietary	Hypoallergenic milk	Protein concentrates
Frozen desserts		Salad oils	Medical	Meat products	Pet foods
Instant milk drinks		Sandwich spreads		Noodles	
Pancake flour		Shortenings	**TECHNICAL USES**	Prepared mixes	**HULLS**
Pan grease extender			**Antifoam agents**	Sausage casings	Dairy Feed
Pie crust		**TECHNICAL USES**	Alcohol	Yeast	
Sweet goods		Anticorrosion agents	Yeast	Beer and ale	
		Antistatic agents			
Roasted Soybeans		Caulking compounds	**Antispattering**	**TECHNICAL USES**	
Candies/confections		Composite building	**agents**	Adhesives	
Cookie ingredient/		material	Margarine	Antibiotics	
Topping		Concrete release		Asphalt emulsions	
Crackers		agents	**Dispersing agents**	Composite building	
Dietary items		Core oils	Paint	Material	
Soynut butter		Crayons	Ink	Fermentation aids/	
Soy coffee		Dust control agent	Insecticides	nutrients	
		Electrical insulation	Magnetic tape	Fibers	
Soybean derivates		Epoxies	Paper	Films for packaging	
Miso		Fungicides	Rubber	Fire fighting foams	
Soymilk		Hydraulic fluids		Inks	
Tempeh		Inks – printing	**Stabilizing agent**	Leather substitutes	
Tofu		Linoleum backing	Shortening	Paints – water based	
		Lubricants	Wetting agents	Paper coatings	
		Metal casting/	Calf milk replacers	Particle boards	
		working	Cosmetics	Plastics	
		Oiled fabrics	Paint pigments	Polyesters	
		Paints		Pharmaceuticals	
		Pesticides		Pesticides/fungicides	
		Plasticizers		Textiles	
		Protective coatings			
		Putty			
		Soap/shampoos/			
		Detergents			
		Vinyl plastics			
		Waterproof cement			

soybeans moved to Korea, Japan, and other parts of Southeast Asia by the first century AD. In the 17th century soybean was introduced into Europe. It was brought into the United States in 1765, then into South America during the mid-1900s (Hymowitz 2004). It is the world's number one oil seed, crop well ahead of rapeseed, cottonseed, peanut, and sunflower seed (Fig. 5). About 80% of the soybeans are produced in North and South America (www.soystats.com). The United States, Brazil, and Argentina are the major soybean-producing countries (Fig. 6).

Soybean is a member of the genus *Glycine* willd., which is a member of the legume family Leguminoseae, subfamily Papilionoideae, and tribe Phaseoleae. The tribe Phaseoleae is the most important tribe of the Leguminoseae, with members that have great importance for food and feed, such as common bean, lima bean, mungbean, and cowpea. Soybeans are divided into two subgenera, *Glycine* (perennials) and *Soja* (Moench) F. J. Herm. (annuals). The subgenus *Soja* includes *Glycine max*, the cultivated soybean, and *G. soja*, the wild annual soybean (Hymowitz 2004). Wild soybean grows in China, Japan, Korea, Russia, and Taiwan in fields and hedgerows and along roadsides and riverbanks. *G. soja* plants are annual, procumbent with slender twining growth, and generally have purple flowers and tawny pubescence. Soybean plants are diploid with 20 pairs of chromosomes on which currently 20 linkage groups (LGs) have been constructed (Hymowitz 2004; Song et al. 2004). The soybean genome consists of ~1.1 Mbp, which is relatively larger than those of Arabidopsis (7.5 times; Mbp/C) or rice (2.5 times; Mbp/C) but smaller than corn (2.4 times; Mbp/C) or wheat (14 times; Mbp/C) (Arumuganathan and Earle 1991).

Cultivated soybean [*Glycine max* (L.) Merr.] was domesticated by humans from wild soybean *G. soja*. *G. max* also has 20 chromosomes ($2n = 40$) and can be intercrossed or hybridized with *G. soja*. Cultivated soybean is morphologically variable because of the development of specific soybean landraces with specific traits by individual farm families throughout East Asia (Hymowitz 2004). Morphological traits are often qualitatively inherited and controlled by a few genes. Plants generally grow erect and are sparsely or densely branched depending on genotype and growing conditions such as day length, soil fertility, plant spacing, and water availability. Leaves are primarily trifoliolate alternatively arranged in two opposite rows with leaflets varying from oblong to ovate to lanceolate in shape. Pubescence on leaves, pods, and stems can be dense to almost absent. Pubescence color is gray, tawny, or light tawny. The root system consists of a taproot and a large number of fibrous, secondary roots. Root nodules are 3- to 6-mm spherical swellings of the root cortex inhabited by *Bradyrhizobium japonicum* bacteria, which establish a symbiotic relationship with the soybean to fix N_2 from the air and supply N to the plant (Lersten and Carlson 2004). Soybean flowers have bilateral symmetry and are white or purple. Seeds are spherical produced in one to four seeded pods with pod walls at maturity colored tan, brown, or black. Seeds of soybean have black, brown, green, yellow, or mottled seed coats and yellow or green cotyledons. However, commercially grown soybeans usually have yellow seed coats and yellow cotyledons. Seed size of commercially grown soybeans are generally 10 to 20 g/100 seeds but can be significantly larger than 30 g/100 seeds or significantly smaller than 6 g/100seeds in size (Lersten and Carlson 2004). Farmers generally plant soybeans in the spring to early summer. During the summer, soybean plants flower and produce 60 to 80 pods, each holding from one to four pea-sized

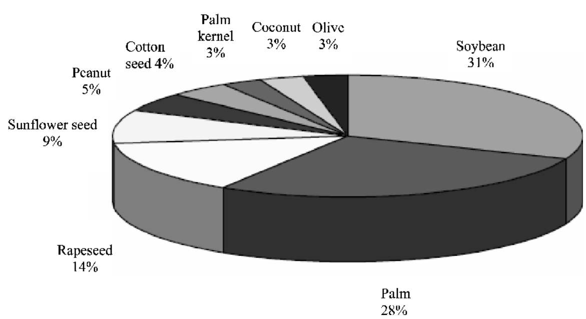

Fig. 2. World vegetable oil consumption 2003 (SoyStats: www.soystats.com/2004)

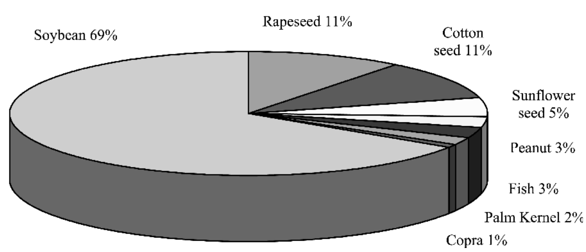

Fig. 3. World protein meal consumption 2003 (SoyStats: www.soystats.com/2004)

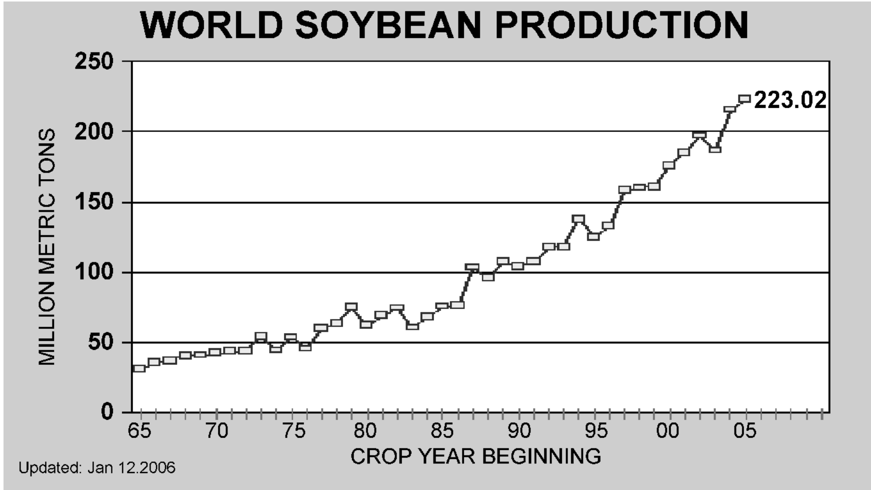

Fig. 4. World soybean production in million metric tons from 1965 to 2006 (projected) (Chicago Board of Trade – www.cbot.com)

beans. In the early fall, farmers harvest their crop for the beans, which are high in protein and oil. In tropical environments, soybeans can be grown year round.

Efforts to seriously improve soybeans through plant breeding did not begin until the 1940s. An effort to improve soybeans through breeding has expanded into all major soybean-growing regions of the world. Most of the improvement has been through conventional breeding practices, but molecular breeding techniques have played a more important role in recent soybean improvements. The most important traits in traditional breeding programs include soybean yield, pest resistance, and seed composition. Improved yield is the most important trait in soybean breeding because it has the most impact on growers' profits (Orf et al. 2004). Estimates indicate that soybean yields are improving at a rate of 23 kg ha^{-1} $year^{-1}$ due to improved varieties, production practices, and higher atmospheric CO_2 (Specht et al. 1999). To insure yield stability over various growing conditions, considerable effort has been made to select for resistance to soybean pathogens such as diseases and nematodes. Tolerance to abiotic stresses such as drought, flooding, and nutrient deficiency or toxicity is also of interest to increase and stabilize yields.

Recently traits that improve the value and functionality of soybeans such as modification of protein and oil to give greater utility in food, health, and industrial uses have been emphasized by soybean breeders. Soybean breeding research has been directed toward modifying the fatty acid profile in the oil to expand uses in food and industrial applications. Modifying soybean oil to lower saturates to less than 7%, increase the oleic acid content to 50 to 60%, and lower the linolenic acid content to <3% would greatly improve soybean quality for greater functionality in food and industrial applications. Other areas of emphasis include improving protein by modifying the amino acid profile, improving digestible phosphorus, and reducing antinutritional factors such as trypsin inhibitors and allergenic factors (Wilson 2004).

Breeding of the self-pollinating soybean includes parental selection followed by hybridization of the selected parents. Parent selection is one of the most important decisions, affecting gene frequencies and genetic variability of populations, which eventually change population means. Germplasm resources for soybean breeding include commercial cultivars, advanced breeding lines, and plant introductions. Depending on breeding goals, parental combinations can be between superior parents for higher mean performance or between an elite line and plant introduction, which will hopefully result in transgressive segregation The genetic base, especially of US cultivars, is narrow and traces back to ca. 15 ancestors. Efforts are being made to utilize more plant introductions in breeding programs to broaden the germplasm base and to introduce new genes for yield, pest resistance, oil quality, and protein quality (Carter et al. 2004).

Procedures following hybridization of the selected parents are to identify desirable individuals or families from segregating generations, which include pedigree- selection, bulk-population, and single-seed-descent methods. The pedigree-selection method is based on practical selection among F_2 plants. The procedure includes making crosses

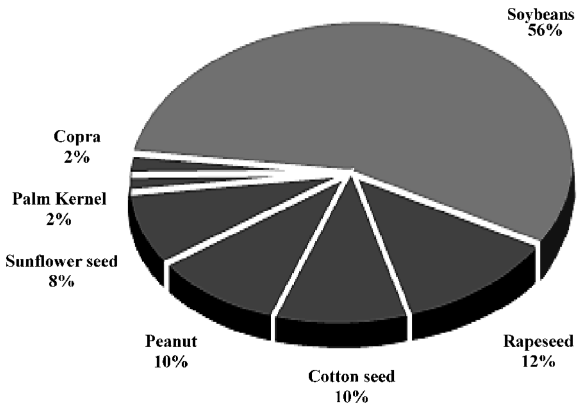

Fig. 5. World Oilseed Production 2003 (SoyStats: www.soystats.com)

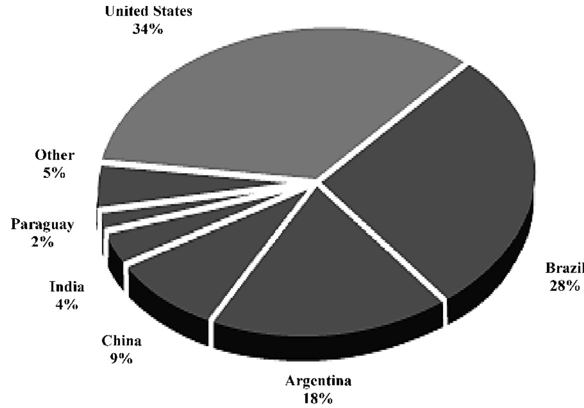

Fig. 6. World Soybean Production 2003 (Soy Stats: www.soystats.com)

among the chosen parents followed by individual plant selections until the desired level of homozygosity is achieved. Usually in the F_4 or F_5 generation, the plant row will be bulked or composited. This seed is then used to conduct preliminary yield tests. A high percentage of the loci are homozygous in the F_3 and F_4 generations, and families are largely homogeneous at this time, which hopefully provides for effective selection among the composited F_4 or F_5 families (Poehlman and Sleper 1995). This method is desirable for selecting qualitative traits that can be identified in the early segregating generations and allows for the elimination of undesirable individuals before testing. Selection in each cycle represents expression of diverse variability from different environments, but this method is labor intensive, requires extensive record keeping of parent-progeny relationships, and is less efficient for quantitative traits.

The bulk-population method is a breeding procedure for advancing segregating populations in bulk until a desired level of homozygosity is achieved. Advancement of the early generations is carried out as bulk populations without regard to individual plant selections. The breeder might allow for natural selection in the early bulk generations. This could be particularly useful for pest resistance if the environment contains natural infestations of the pest. Another example where bulk-population breeding could be successful is in the selection for seed size. Segregating populations could be harvested and desirable seed size selected for advancement in the next bulk generation. The procedure in this method is to keep planting and harvesting seeds in bulk until F_3 or later generations, then plant individual spaced-plants, single-plant thresh, finally, grow the plants in progeny rows. Progeny rows would likely be F_5 but could be earlier or later generations depending upon the objectives and resources available (Poehlman and Sleper 1995). Compared to pedigree selection, the bulk-population method is simpler and less labor intensive. Natural selection can be very effective in the bulk-population method, particularly in breeding for certain biotic or abiotic stresses, by eliminating undesirable genotypes in early segregating generations.

The most favored selection method in soybean cultivar development is the single-seed-descent (SSD) method. In soybean, single pod descent (SPD) modified from the SSD has been used in which one or a few pods from a single plant are harvested and bulked to grow the next generation. The procedures for the SPD method include bulking seeds in the F_1 and harvesting one or a few pods per plant in early segregating generations until the desired level of homozygosity is achieved. After the desired level of homozygosity is achieved, perhaps in the F_4 generation, plants are single-plant threshed and seed from each plant seeded to a progeny or plant row (Poehlman and Sleper 1995). Selected progeny rows are bulked and yield-tested in the following generation. Advancement toward homozygosity can be hastened through the use of winter nurseries. One of the major disadvantages of the single-seed-descent method is the narrow exploitation of the F_2 generation where only one seed or pod represents the genetic base of the F_2 population. However, single-seed descent is more often the method of choice for variety development because it is often less expensive and less labor intensive than other methods.

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